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Volume Sensor Development Test Series 4 Results — Multi-Component Prototype Evaluation

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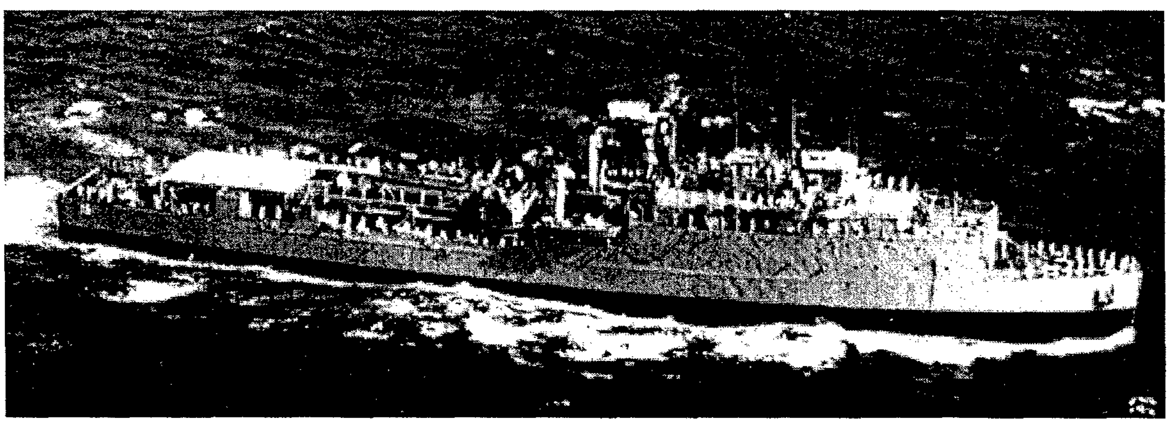

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14. ABSTRACT

The Volume Sensor prototype consisting of regular and long wavelength video cameras with machine vision, spectral sensors, and microphones integrated with data fusion and alarm algorithms was evaluated for improved situational awareness in a full-scale test. The test series evaluated the prototype sensor suites and alarm algorithms onboard the ex-USS *SHADWELL*. The tests established the detection system performance with regard to various fire and nuisance sources, pipe ruptures, and environmental conditions that may occur onboard ship. The integration of the Volume Sensor components into a functioning prototype was a success. The individual components identified the events and communicated their alarms to the Fusion Machines. The Fusion Machines incorporated data fusion algorithms that synthesized information from the sub-system components to improve performance. The Fusion Machine performed very well, demonstrating the ability to discriminate against nuisance sources and to alarm to smoldering and flaming fires and to pipe ruptures.

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VOLUME SENSOR DEVELOPMENT TEST SERIES 4 RESULTS –
MULTI-COMPONENT PROTOTYPE EVALUATION

1.0 INTRODUCTION

The Advanced Damage Countermeasures (ADC) program is developing and demonstrating improved Damage Control (DC) capabilities. An important element of the ADC Program is the development of a Volume Sensor system that can assess damage conditions within a space without relying on point detection or spot-type smoke detectors. The program is known as the Volume Sensor (VS) Program. The first phase of this program (FY01) consisted of a literature review and an industry review of current and emerging technologies [1]. Based on the FY01 work, several technologies were identified as having potential for meeting objectives of the Volume Sensor development effort. Work preformed during FY02 provided a basis for moving forward with the use of video image detection (VID) for shipboard applications [2]. The test results indicated that the VID systems using smoke alarm algorithms could provide equivalent or superior detection compared to spot-type smoke detectors for most of the conditions evaluated.

One task of the FY03 work was to evaluate video-based fire detection systems onboard the ex-USS *Shadwell*, the Naval Research Laboratory full-scale fire research facility in Mobile, Alabama [3]. The first test series was Test Series 2 of the CVN 21 Fire Threat to Ordnance program conducted April 7-18, 2003 [4]. During these tests, the video image fire detection systems were evaluated in an environment designed to represent magazine storage onboard ships while exposed to two fire scenarios: adjacent space fires and in-space, wood crib fires [5]. Due to the limited fire scenarios that were conducted during the Magazine Test Series 2, a separate test series was conducted specifically for the Volume Sensor (VS) program to provide a broader range of fire and nuisance source exposures. This additional test series (Test Series VS1) was conducted on the ex-USS *Shadwell* on April 21-25, 2003 [6]. Analysis of the data from these shipboard tests indicated potential issues with VID performance relative to camera settings. These tests also were useful in identifying potential advantages for the use of various spectral and acoustic measurements as signatures of normal, fire, and nuisance events [7-11]. Additional tests were conducted at the Navy Wet Trainer in Baltimore, Maryland to record acoustical emissions and video of a range of pipe rupture and flooding events [12].

The VS2 test series [13] evaluating the performance of the video image fire detection systems under varying light conditions and camera settings in a mock ship environment was conducted at Hughes Associates between August 2003 and January 2004. This test series expanded on the previous FY03 Test Series VS1 conducted on the ex-USS *Shadwell*, mentioned above [5, 6]. In addition, spectral and acoustic sensors were utilized to measure potential event signatures that could be integrated with the VID technology to expand the capabilities and to compensate for deficiencies with the current video image fire detection systems used for Navy applications. The data collected were used to develop algorithms for the Volume Sensor system.

A multi-component prototype was developed during the first three quarters of FY04. This first VS prototype system consisted of suites of co-located sensors and fusion algorithms

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evaluated aboard the ex-USS *Shadwell* in July of 2004. The test series demonstrated the ability of the various components to successfully work in unison and detect and discriminate various sources. The integration of the Volume Sensor components into a functioning prototype was a success. The components detected event conditions and communicated the alarms and alarm times to the Fusion Machines. In addition both Volume Sensor prototypes outperformed the individual sensor system components in terms of both event detection and nuisance rejection. Despite the success of the Volume Sensor system prototype as a whole, the VS3 test series also revealed poorer than expected performance of the VID systems [14] and highlighted areas for continued algorithm improvements. Based on the results collected from the VS3 test series, developmental improvements were made at both the component level and the fusion system level of the Volume Sensor prototype system. The VS4 test series discussed in this report was used to assess the developmental progress of the prototype system and to expand the database of scenarios and sensor measurements.

2.0 OBJECTIVES

The objective of this test series was to evaluate prototype sensor suites and alarm algorithms onboard the ex-USS *Shadwell* in preparation for demonstrating a multi-component Volume Sensor system in FY05. In particular, the tests were designed to assess the developmental progress of the prototype system since the Test Series 3 evaluation in July 2004 and to expand the database of scenarios and sensor measurements. These data are to assist in identifying the most effective use of sensors within a space as part of the Volume Sensor system (i.e., should the sensors be clustered together or distributed throughout the space).

3.0 APPROACH

The objectives were achieved by conducting full-scale experiments aboard the ex-USS *Shadwell* in Mobile, AL [3]. This test series consisted of small fires, adjacent space fires, various nuisance sources and pipe ruptures that challenged the detection systems. Three prototype sensor suites and two Fusion Machines containing algorithms to be tested were installed. The performance of the Fusion Machines and the VID systems were compared to the response of commercial off the shelf (COTS) smoke detection technologies.

4.0 TEST SETUP AND TEST PROCEDURES

The tests were conducted in and around the mock magazine on the 3rd deck of the ex-USS *Shadwell*. Figure 1 shows the layout of the space in the vicinity of the 3rd deck magazine and Table 1 presents the overall dimensions of the compartment. A summary of the proposed test setup is provided in the following sections. In general, the test setup was the same as that of Test Series VS3.

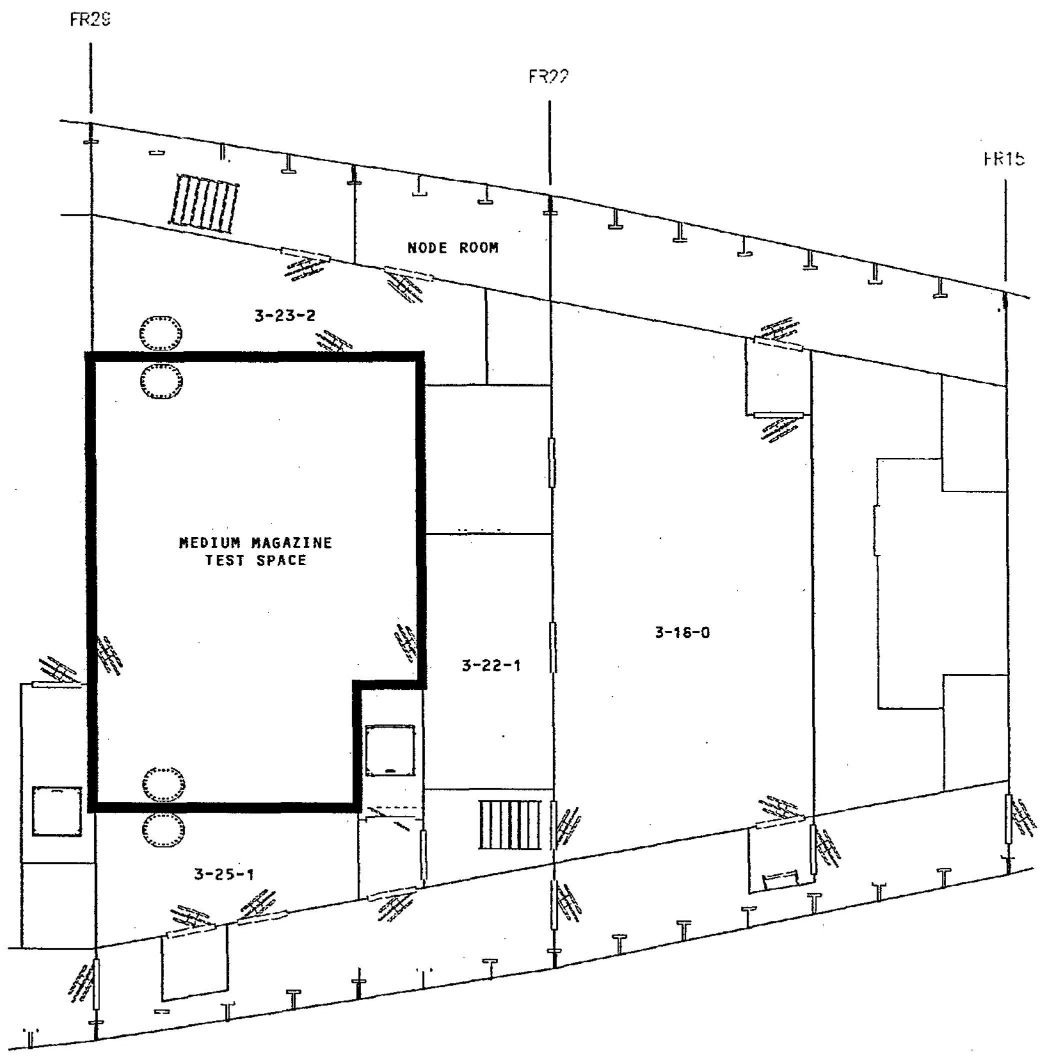

Fig. 1 — Ex-USS *Shadwell* 3rd deck magazine area

Table 1 — Overall Dimensions of Test Compartment

Test Space	Length (m (ft))	Width (m (ft))	Height (m (ft))	Volume (m^3(ft^3))
3rd Deck Magazine	5.9 (19.5)	8.1 (26.5)	3.0 (10.0)	143.4 (5,167.5)

4.1 Test Spaces

For this test series, a mock magazine on the 3rd deck of the ex-USS *Shadwell* was used as the test space. Though this test space has been designated as a magazine because of previous test programs, the designation is not relevant in this evaluation, but is used for simplicity due to the familiarity of the name among test participants and ship's force. The space serves as a generic ship compartment with several features that provide challenges to fire detection. The magazine that was used in this test series has been used for previous detection technology tests [4-6], and it is comparable in size to the compartment used in the laboratory evaluation of the Volume Sensors [13]. A vestibule located in the forward, starboard corner of the space that measured 1.1 m x 2.2 m x 2.6 m high (3.7 ft x 7.3 ft x 8.5 ft) was not part of the test space.

The magazine test space had overhead beams spanning port to starboard at 1.2 m (4.0 ft) spacing and depths of 31 cm (12 in), Figs. 2 and 3. In addition, a 50 cm (20 in) deep longitudinal beam bisects the compartment into two distinct zones. These deep beams impeded smoke spread and provided a challenge to spot-type smoke detectors and VID systems.

Compartment 3-23-2, port of the magazine, was used to stage some of the computer systems and hardware related to the Volume Sensor prototype system and detection systems discussed in Sections 4.6.6 and 4.7.3.

4.2 Obstructions

In addition to the overhead beams, light fixtures, and a partial overhead grid in the 3rd deck magazine, ductwork was added to the overhead. Obstructions, in the form of cabinets, were also placed on the deck within the compartment. The obstructions blocked the view of the optical components providing a challenge to the VS prototype detection system. The cabinets were approximately 1.83 m (6 ft) in height and dispersed throughout the compartment. Figure 2 shows the layout of the cabinets within the 3rd deck magazine. Circular ventilation duct (15.2 cm (6.0 in) diameter, 1.5 m (5.0 ft) long sections) were placed in the overhead on the grid as shown in Fig 3. In addition to the cabinets a large vertical LPES ventilation shaft runs through the test compartment. All obstructions were of the same size and in the same positions as tested in Test Series VS3.

4.3 Lighting

Lighting was installed in the overhead of the test compartments to provide typical illumination for various spaces onboard naval ships (see Fig. 4). The lighting system was installed in accordance with DOD-HDBK-289 [15]. The lighting was suspended approximately 0.3 m (12 in) below the overhead, making the fixtures flush with the overhead beams. Once the lighting system was complete a photometric survey was conducted to document the uniformity and level of illumination at 0.76 m (30 in) above the deck. A height of 0.76 m was used to comply with DOD-HDBK-289 section 4.1.3. The photometric survey used a light meter [Extech model number 401025]. The meter was capable of measuring up to 5000 foot-candles (Fc) with a measuring resolution of 0.1 for the 0-200 Fc range. The procedure for mapping the illumination level consisted of mounting the photometer on a tripod to ensure a height of 0.76 m and mapping the space via 0.6 m x 0.6 m (2 ft) squares. The cabinet obstructions and overhead ducting were removed from the test space so no light was obstructed from entering the wide viewing angle (~180 degrees) of the photometer. Photo surveys were taken before and after the test series. The average illumination level within the compartment was 6.7 Fc with a standard deviation of 2.1 Fc.

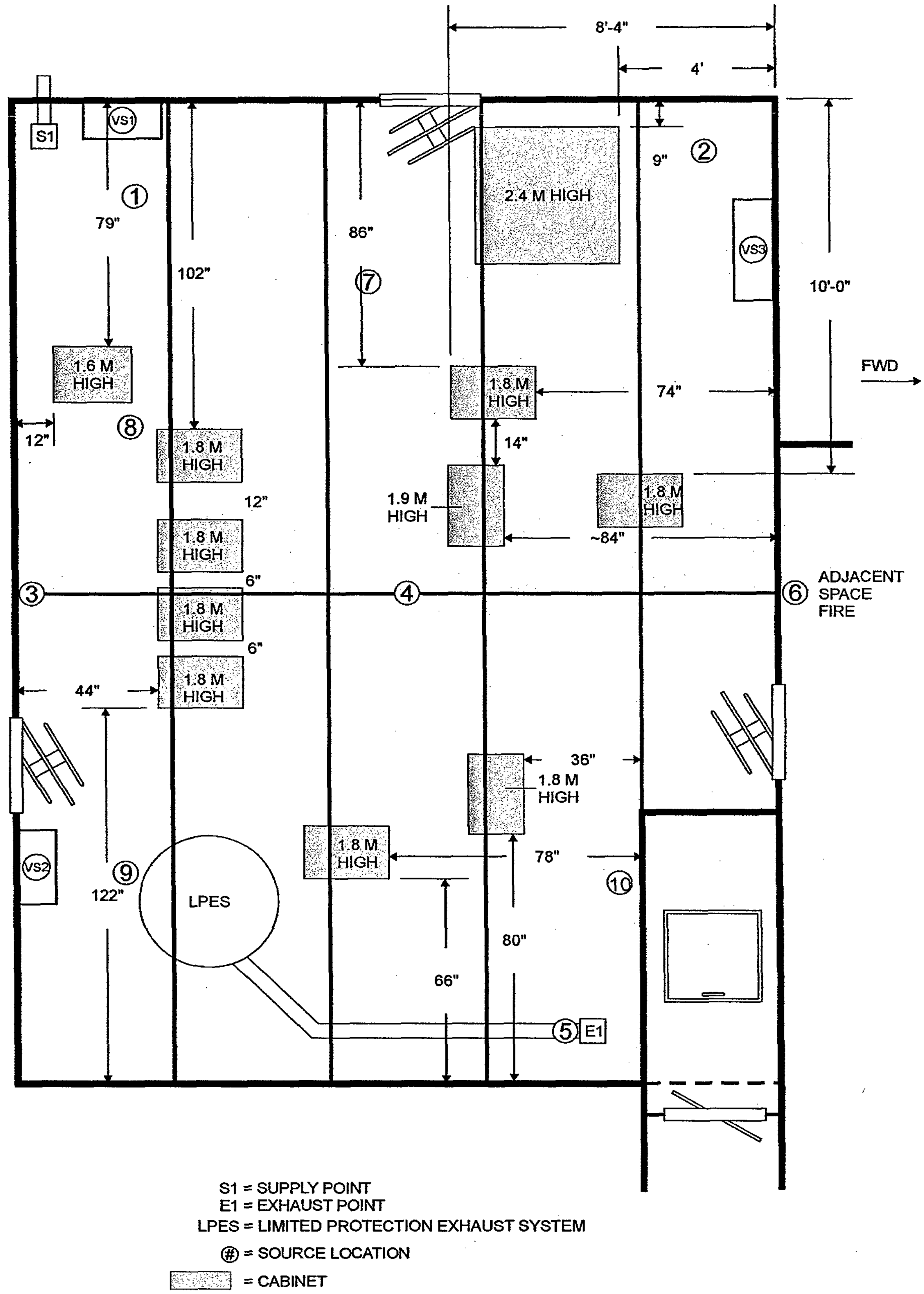

Fig. 2 — Layout of deck obstructions within 3rd deck magazine

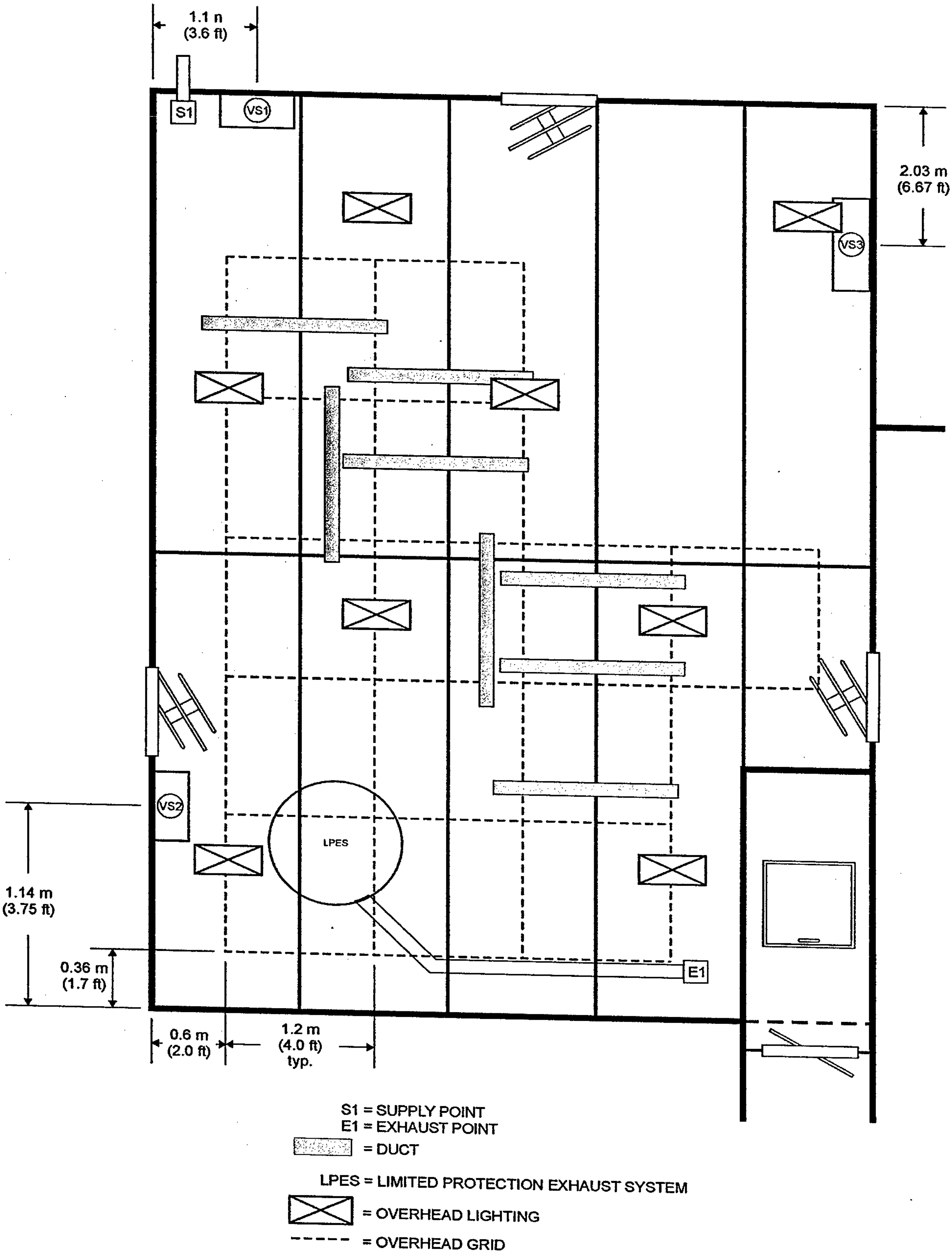

Fig. 3 — Layout of overhead obstructions within 3rd deck magazine

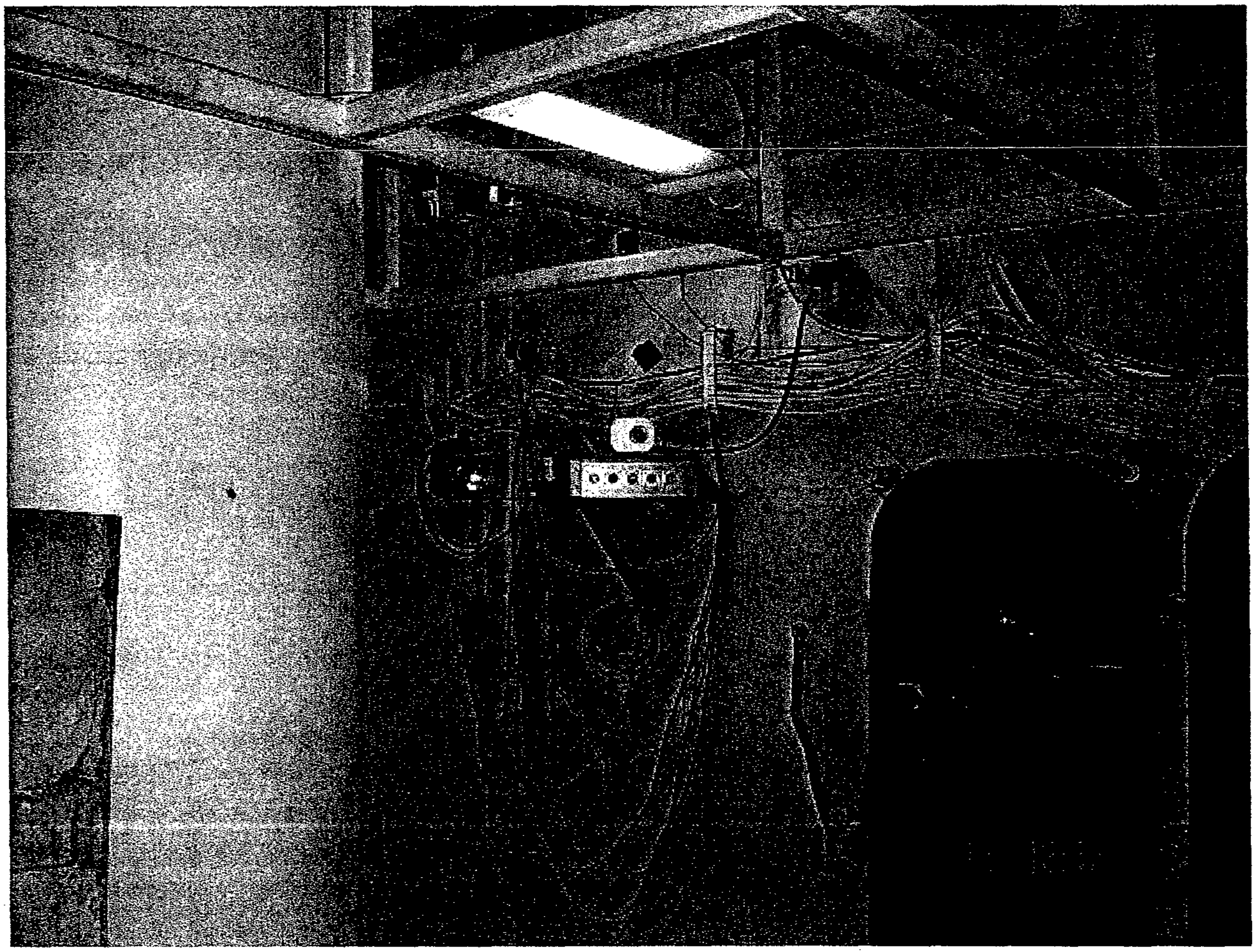

Fig. 4 — Photo of Volume Sensor Suite #2 in test compartment under illumination level (~6.7 Fc)

4.4 Ventilation and Closures

All fire tests in the magazine were conducted with mechanical ventilation typical of those found on Navy ships for general spaces [16]. During the majority of tests the ventilation system supplied approximately 5 air changes per hour (ACH) or 380 cfm in the magazine. Supply air was introduced in the aft, port overhead corner of the compartment and air was exhausted from the forward, starboard overhead corner of the compartment, as shown in Fig. 2. The magazine doors were closed during each test, except for two nuisance tests, VS4-016 and VS4-064, in which the WTD 2-29-1 was open to allow exhaust from a forklift to enter the space. A number of the nuisance source tests were conducted without ventilation in order not to dilute the source signature and some sources were run with the ventilation on a slightly higher flow rate, in which nearly 400 cfm was supplied.

4.5 Event Sources

A variety of fire, nuisance, pipe rupture and gas release sources were created to expose the VS prototype and spot-type detectors to a range of potential shipboard scenarios. Small fires were used to challenge the detection systems and provide performance results for early detection. Tables 2 to 6 present details of the fire sources, nuisance sources, the pipe ruptures, gas releases and other developmental scenarios, respectively, that were used in this test series. The source locations are shown in Fig. 2. Locations 1 – 5 and 7 – 8 were used for fire and nuisance sources, Locations 4, 9, and 10 were used for pipe ruptures, while Location 6 was only used for the bulkhead heating tests (Fire Source 9). Most of the sources were conducted at deck level. The height of the electrical cable fires was varied to provide both a range of test conditions and representative shipboard scenarios.

A number of the nuisance sources involved people moving about the space. Although these events were video taped, a general, timed sequence of movements was established so as to accurately document the location of the people/nuisance sources during the event. This procedure and documentation assists in the post-analysis of the data from non-video based sensors. Appendix C contains the times associated with significant events recorded during each test.

Pipe ruptures were simulated with a range of flow rates and leakage areas to challenge the VS prototype. A sprinkler head, water mist nozzle, and a gashed section of pipe were used to provide a varying range of potential rupture effects. Table 4 describes the scenarios used. Water releases were conducted in the test space at three locations (4, 9, and 10). Location 9 was approximately 1 m (3.281 ft) off the deck on the starboard side of the compartment, aft of the vertical LPES ventilation shaft. Some Pipe rupture tests were conducted approximately 1 m (3.281 ft) off the deck and in the overhead, approximately 2 m (6.562 ft) off the deck at location 4. Pipe ruptures were also conducted at location 10, approximately 1 m (3.281 ft) off the deck. The tests systematically varied the objects for which the water impacted upon discharge. Impact targets included open space above the deck, metal cabinets, bulkheads, a mattress and cardboard boxes.

4.6 Prototype Volume Sensor Components

Three prototype sensor suites were used in the current test series. Figure 4 shows one such sensor suite installed in the compartment. The sensor suites were placed at the locations in the test compartment shown in Fig. 3. The sensor suites were numbered 1 though 3. Sensor suite 1 was located on the port bulkhead 1.09 m (3 ft 7 in.) from the aft bulkhead at a height of 2.44m (8.0 ft). Sensor suite 2 was located on the aft bulkhead 1.14 m (3 ft 9 in.) from the starboard bulkhead at a height of 1.84 m (6 ft 0.5 in.). The 3rd sensor suite was located on the fwd bulkhead 2.03m (6 ft 8 in.) from the port bulkhead at a height of 2.54m (8 ft 4 in.). Each prototype sensor suite included four components: a CCTV video camera (cameras 4-6), a bullet camera with a long wavelength (near infrared) filter (cameras 1-3), a microphone, and a set of single element optical sensors from the original Spectral-Based Volume Sensor (SBVS) test bed studied in previous test series [13,14].

Table 2 — Fire Sources

No.	Fire Scenario	Description
1	Flaming Cardboard Boxes with Polystyrene Pellets	Four 0.26 x 0.26 x 0.11 m (10 x 10 x 4.5 in.) boxes were arranged in two parallel rows, with the 0.26 x 0.26 m (10 x 10 in.) sides facing the opposite row. The boxes were loosely filled with polystyrene packing pellets leaving approximately 2.5 cm (1.0 in.) of space to the top of the box. A 2.5 cm (1.0 in.) flue space was provided between the rows. A butane lighter was used to light the flap of one corner of a box half way up the flue space so that flames propagated up the flue space and involved both rows.
2	Flaming Trash Can	One 61 x 84 cm O.D., 32 L (24 x 33 in O.D., 12-16 gal) plastic trash bag was approximately half filled with trash (20 crumpled paper towels, 20 crumpled tissues, three 12 oz plastic soda bottles, a 3 oz stick of deodorant, three cotton rags (36 x 36 cm (14 x 14 in.)) and a folded newspaper (10 full sheets). The trash bag was then placed in a metal trash can. The open bag of trash was lit at the top with a butane lighter.
3	Flaming Shipping Supplies	Three 4 L (1 gal) polyethylene bottles were placed on top of a 0.3 x 0.3 m (1.0 x 1.0 ft) section of wood pallet. Plastic shrink wrap was wound around this assembly four times. A 5 x 5 x 5 cm (2 x 2 x 2 in.) pan was filled with isopropyl alcohol (IPA) and positioned inside the pallet so that it impinged on both the wood slat and plastic bottles above. A butane lighter was used to ignite the IPA.
4	Flaming IPA Spill Fire	A 0.25 L (8.5 oz) spill of IPA on the deck was ignited with a torch. A bag of trash, as defined in the Flaming Trash Can scenario, was situated on the edge of the fuel spill. The bag of trash was intended to provide a sustained fire source in case that the detectors did not alarm to the IPA spill fire alone.
5	Smoldering Mattress and Bedding	One 0.3 x 0.3 m (1.0 x 1.0 ft) section of Navy mattress (MIL-M-18351F(SH), 11 cm thick Safeguard polychloroprene foam core covered with a fire retardant cotton ticking) was under a stack of bedding, including one polyester batting, quilted mattress pad (Volunteer Blind Industries, GS-07F-14865, DDD-P-56E), one bed sheet (Federal Specification DDD-S-281) and one brown bedspread (Fed Spec DDD-B-151) (each 0.6 x 0.6 m (2.0 x 2.0 ft)). One 500 W cartridge heater (Vulcan, TB507A) energized at 85 VAC was located between the bedding and the mattress. The whole assembly was placed on a metal rack measuring 45 x 45 x 20 cm high (17.5 x 17.5 x 8 in.). The voltage of the cartridge heater was raised to 100 VAC 15 minutes into the test and the cartridge was moved to virgin material. Except for test VS4-003, in which the bedding was folded in 0.3 x 0.3 m squares and stacked on top of the mattress, the 0.6 x 0.6 m bedding pieces were loosely draped over the mattress.
6	Smoldering Cable Bundle	A bundle of cable consisting of five 30 cm (12 in.) long pieces of Navy low-smoke cable (Monroe Cable Co., LSTSGU-9, M24643/16-03UN XLPOLYO cable) was placed in a horizontal orientation. One 500 W cartridge heater (Vulcan, TB507A) was placed in the middle of the bundle and energized to 84 VAC (70% of 120 V max). The power was increased to 100 VAC after approximately 25 minutes and further increased to 120 VAC 35 minutes after power was initiated.

Table 2 — Fire Sources (Continued)

No.	Fire Scenario	Description
7	Smoldering Laundry	Six cotton rags (36 x 36 cm (14 x 14 in.)) were folded into quarters and loosely piled one on top of another. The resulting footprint of the pile was 18 x 18 cm (7 x 7 in.). One 500 W cartridge heater (Vulcan, TB507A) was placed in the center of the pile and set to 96 VAC (80% of 120 V max).
8	Smoldering Oily Rags	Five cotton rags, approximately 36 x 36 cm (14 x 14 in.), each soaked with 30 mL (1 oz) of 10W30 motor oil were crumpled and tossed into a metal trashcan. One 500 W cartridge heater (Vulcan, TB507A) was inserted into a 2.5 cm (1.0 in.) diameter hole 2.5 cm (1.0 in.) from the bottom of the trash can and placed on top of one rag. The remaining rags were loosely piled on top of the heater. Using a variable transformer, the cartridge heater was initially energized to 85 VAC.
9	Painted Bulkhead Heating	The forward bulkhead of the test space was painted with one coat of white chlorinated alkyd enamel paint (DOD-E-24607A). A heptane spray fire in the aft, port corner of compartment 3-22-1 heated the painted bulkhead, causing the paint to off gas in the test space. Two industrial spray nozzles (Bete Fog Nozzles, model FF033) were connected to the heptane fuel system, which was pressurized from 172 kPa (25 psi) up to 552kPa (80 psi). Appendix A includes additional details on the fuel system.
10	Shielded IPA pan fire	An open box consisting of three sides measuring 0.61 m by 0.61 m (2ft by 2 ft) was fabricated. The box contained two sides and a top so when positioned in the compartment the deck formed the base and two sides of the box were missing providing access to the interior of the box. A 0.3048 m by 0.3048 m (1ft by 1ft) pan with approximately 1.5L of methanol was placed in the interior of the box flush with the corner. When ignited the flames from the methanol pool fire heated the three surfaces of the box. At peak burning, there was short extension of flame beyond the top of the box enclosure.

Table 3 — Nuisance Sources

No.	Nuisance Scenarios	Description
1	Torch Cut Steel	A 0.6 x 0.6 m (2.0 x 2.0 ft) sheet of steel with 3 coats of chlorinated alkyd enamel paint (DOD-E-24607A) was cut with an oxyacetylene torch.
2	Welding	A 0.6 x 0.6 m (2.0 x 2.0 ft) sheet of steel with 3 coats of chlorinated alkyd enamel paint (DOD-E-24607A) was welded using an arc welder and 0.32 cm (0.125 in) number 7018 rods. The Amperage was varied depending on the test and the number of rods consecutively used was varied.
3	Grinding Painted Steel	A 0.6 x 0.6 m (2.0 x 2.0 ft) sheet of steel with 3 coats of chlorinated alkyd enamel paint (DOD-E-24607A) was ground with an 11 cm (4.5 in.) power hand grinder for approximately 5 minutes or more.
4	Toaster: Normal Toasting	Four slices of white bread was toasted in a Magic Chef (model N-10) 120V, 1500W toaster at the darkest setting for two cycles then repeated with new bread inserted into the toaster.
5	Engine Exhaust	Exhaust from a diesel-powered engine (Yanmar, Engine #69914, engine output is 2.8 kW (3.8PS/3600), max output 3.1 kW (4.2PS/3600), displacement 0.199L) was allowed to flow into the test area.
6	People Working in Space	Multiple people working in view of the cameras. This work included cleanup of water in the space and sweeping the deck. Duration was test dependant.
7	Waving Materials	Waving a white cotton rag. The material was waved, shaken, and folded by a person moving through the space and stopping in front of each camera for a short period of time (minimum 30 sec)
8	Spray Aerosol	A five second spray interval at multiple locations in the test space by two aerosols. The aerosols used were: 1) Old Spice High Endurance deodorant 2) Lysol disinfectant spray.
9	Spilling Metal Bolts	A bin of 1/4 in. metal bolts was spilled on the deck. The height of the drop was approximately waist high and the rate of spill was varied between slow (~5 bolts per second) to fast (all the bolts ~100 in 2 seconds)
10	Space heater	Operation of a one-setting Fostori Sun-mite space heater [model number SHK-212-1CA] at various locations.
11	Heat gun	A heat gun [Master heat gun make, and model HG-501A] was activated in 30 second intervals at multiple locations in the test space.
12	Flash photography	Both single camera and multiple camera flash photography were executed in the space, both in the view and out of the view of the cameras.
13	AM/FM Radio	A radio was turned on and off and cycled through multiple talk and music stations. A tape player was also used during testing to play heavy metal music.
14	VHF Radio	Personnel with ship radios were walked through the test space while talking and receiving messages.
15	TV	A television in the test space was turned on with varying noise levels and a video tape was played.

Table 4 — Pipe Ruptures

No.	Pipe Rupture Scenarios	Description
1	Water Aerosol (Mist)	A water mist nozzle (Bete P24, k value of 0.0158) flowing at approximately 44-149 psi (0.105 to 0.193 gpm) was used to simulate a pressurized pipe puncture/fitting rupture.
2	Pipe Rupture (gash)	A section of 2.5 cm diameter (1 in.) pipe with a gash (25 cm by 0.3175 cm (10 in. by 0.125 in.)) was oriented vertically and supplied with water at 40 psi.
3	Pipe Rupture (no nozzle head)	Water was released from a 2.5 cm (1 in.) diameter pipe at 40 psi, replicating a severed vertical pipe. The water was discharged downward from a height of approximately 1 m (3.281 ft) above the deck.
4	Pipe Rupture (nozzle head)	Water was released from a pipe with a sprinkler head (TF29180-28, k value of 3.91) attached to disperse the water, replicating a fractured pipe. Water pressure was 40 psi (~25 gpm). The sprinkler head was pendant mounted, 1 m (3.281 ft) above the deck.

Table 5 — Gas Releases

No.	Gas Release Scenarios	Description
1	Gas Release (N2)	A nitrogen tank with regulator supplied gas at 50 psi and 125 psi to 0.6 cm dia. (0.25 in.) copper tubing run into the compartment with the end of the tubing open to atmosphere.
2	Gas Release (Air)	An air hose with a release handle (manual valve) was used in the test compartment to release air into the compartment atmosphere. The line was pressurized to 85 psi.
3	Gas Release (N2) (small orifice)	A nitrogen tank with regulator supplied gas at 50 psi and 125 psi to 0.6 cm dia. (0.25 in.) copper tubing terminating in a 0.6 to 0.16 cm (0.25 to 0.0625 in.) reducing fitting that discharged gas directly to atmosphere.
4	SCBA	The valve on a self contained breathing apparatus (SCBA) mask was released to allow free flow of gas into the atmosphere.

Table 6 — Developmental Sources

No.	Developmental Scenarios	Description
1	Lighting off	Lighting in the compartment was on during the baseline data acquisition then the lighting in the compartment was turned off (no source was run).
2	Lighting on	Lighting in the compartment was off during the baseline data acquisition then the lighting in the compartment was turned on (no source was run)
3	Lighting off (Trash can fire)	Lighting in the compartment was off during the entire test. After the baseline data collection, a trashcan fire was ignited at location 2.
4	Lighting off (Flaming Cardboard Boxes with Polystyrene Pellets)	Lighting in the compartment was off during the entire test. After the baseline data collection, a flaming cardboard boxes with polystyrene pellets was ignited at location 2.
5	Lighting on/off (Trash can fire)	Lighting in the compartment was on during the baseline, and then after 240 seconds the lighting was turned off, 60 seconds after the lights were shut off a trashcan fire was ignited at location 2.
6	Lighting on/off (Flaming Cardboard Boxes with Polystyrene Pellets)	Lighting in the compartment was on during the baseline, and then after 240 seconds the lighting was turned off, 60 seconds after the lights were shut off a flaming cardboard boxes with polystyrene pellets was ignited at location 2.

Data from the instruments in the prototype sensor suites were processed by the individual sensor subsystems of the Volume Sensor prototype. These subsystems included a visible spectrum VID system, a long wavelength video detection system (LWVD), an SBVS detection system, and an acoustics detection system (ACST). The processed data and some pre-selected and normalized raw data were sent from the subsystems to a Fusion Machine, the final component of the Volume Sensor prototype. The Fusion Machine provided further analysis using the data fusion algorithms. The alarm information generated by the Fusion Machine constituted the primary output of the Volume Sensor prototype. The top of Table 7 lists the Volume Sensor prototype components, Fig. 4 shows an installed sensor suite, and Fig. 5 displays a diagram of the Volume Sensor prototype. More information is available in reference [17]. Sections 4.6.1 through 4.6.6 describe the components of the Volume Sensor prototypes used in this test series. The other systems listed in Table 7 were used as a bench mark of performance.

4.6.1 Volume Sensor Prototype Fusion Machines 1 and 2

Two Volume Sensor prototypes were used in the current test series. Both prototypes used the same LWVD, ACST, and SBVS detection systems while using different systems for the visible spectrum video image detection (VID). One prototype employed the Fastcom Smoke and Fire Alert (SFA) commercial VID system; the other prototype used the axonX SigniFire commercial VID system. Two custom-built PCs with AMD Opteron 64-bit processors were used as Fusion Machines to implement data fusion algorithms for each prototype. Fusion Machine 1 (FM1) analyzed data from the SFA, LWVD, SBVS, and ACST sensor subsystems. Fusion Machine 2 (FM2) analyzed data from the SigniFire, LWVD, SBVS, and ACST sensor subsystems.

Table 7 — Detection Systems and Instrumentation

Device/Instrument	Manufacturer/details	Data Acquisition
Volume Sensor multi-component prototype suite (Qty = 3)	Sony SSC-DC393 camera (3) Long wavelength NIR camera (3) Microphone (Shure MX-393 (2) and Shure MX-202 (1)) SBVS sensor suite (3)	Coax to splitters (VID) Coax to splitters (LWVD Software on DVR) NRL 7120 equipment. Signal conditioning and Pentium 3 PC. NRL 6110 data acquisition and cables.
Smoke & Fire Alert (SFA) Video flame and smoke detection system	Fastcom	Independent PC received 6 video inputs from splitters and produces digital output to Fusion Machine 1 via network.
SigniFire Video flame and smoke detection system	axonX	Independent PC received 6 video inputs from splitters and produces digital output to Fusion Machine 2 via network.
Volume Sensor Fusion Machine (FM) (Qty = 2)	PC with fusion alarm algorithms (1 system for each VID system)	Inputs from a VID system, SBVS sensor system, ACST system and LWVD system via network. Direct inputs from all standard and NIR video cameras.
Ion detector (Qty = 4) Photoelectric detector (Qty = 4) Multi detector (Qty = 4)	EST SIGA-IS EST SIGA-PS EST SIGA-IPHS	EST3 Panel Individual alarms monitored via 12 panel output relays to Masscomp.
Laser optical density meters (ODM) (Qty = 5)	880 nm infrared LED and receptor over a 1.0 m (3.3 ft) path length	Masscomp
White light optical density meters (ODM) (Qty = 2)	Low-voltage spot lamp (GE 4515) spaced 1.5 m (5.0 ft) from a barrier layer photovoltaic cell (Hyugen 856-RR)	Masscomp (Supplied with 3V and 3 amps)
Overhead gas thermocouples (Qty = 4)	Type K, bare bead	Masscomp
Air thermocouples (Qty = 6)	Type K	Masscomp
Fwd Blkhd thermocouples (Qty = 20)	Type K	Masscomp

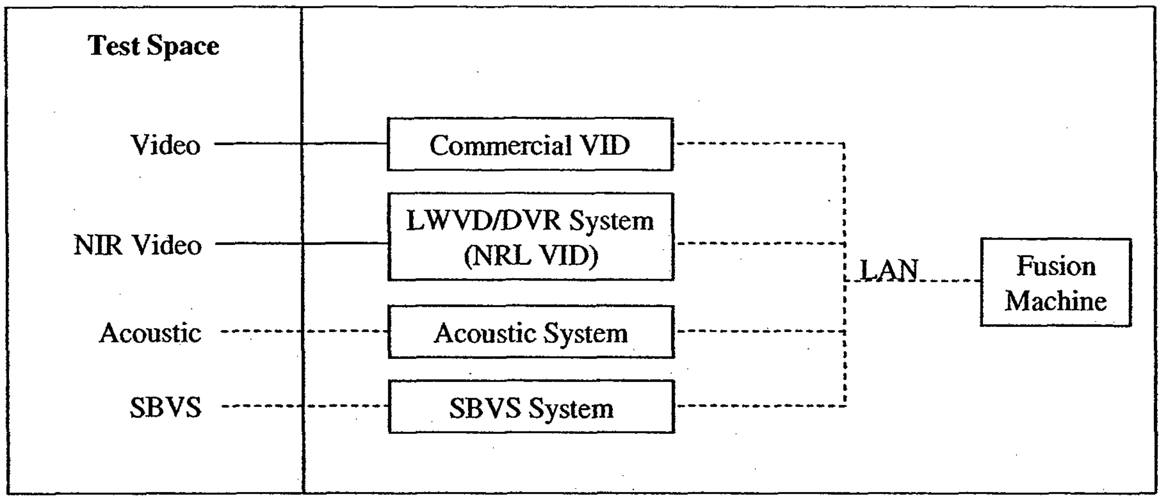

Fig. 5 — Diagram of Volume Sensor prototype system components

Control of the sensor subsystems, as well as the graphical user interface for each prototype, was implemented separately in software programs running on each Fusion Machine. These programs were referred to as the CnC and GUI programs, respectively, and worked together to process, display and log data from the components of the prototypes. The CnC software implemented a protocol of extensible market language (XML) message packets sent via user datagram protocol (UDP) over the ship's transmission control protocol/internet protocol (TCP/IP) network to control the sensor subsystems and to gather their data to the Fusion Machines at one-second intervals. Details of the protocol are available in reference [18]. The software of the Data Fusion Algorithm Module (DFAM), implemented as an internal class library of the CnC software, performed the processing of the sensor data. The GUI software displayed video from all cameras and data from the sensor subsystems and data fusion algorithms, and also provided an interface for human control of the Volume Sensor prototype. Further documentation on the CnC and GUI software is in references [19 - 21].

The CnC and GUI software generated several log files to record the incoming and processed sensor data, and the event history of the test. The CnC software maintained a sequential log file recording all command and control events and sensor data packets received. The CnC software also created a separate "replay" log file for each test that can be used to replay the test on a Fusion Machine at a later date. This feature can be used for post-processing of refinements to the data fusion algorithms and for off-line debugging of the CnC/GUI interface. The Data Fusion Algorithm Module generated its own sequential event history log file, in addition to logging all incoming sensor data in a format especially suited to further algorithm development. The GUI software also logged all data packets received from the CnC software, and all user interactions.

4.6.2 Volume Sensor Algorithm Development

The first goal for Volume Sensor algorithm development was the design of a flexible and extensible format for the data gathered and processed by the sensor systems. A tree-like structure, dubbed the "Sensor Gestalt," achieved this goal for the CnC software, while a linear structure of state vectors, parsed from the Sensor Gestalt and better suited to pattern recognition techniques, achieved this for algorithm development.

The second goal for Volume Sensor algorithm development was the improvement of the Volume Sensor prototype in the areas where past performance of the sensor systems was weakest. For the various event types, the probabilities of detection (P_d) and probabilities of false alarm (P_{fa}) were calculated for the sensor systems from the data generated during the previous CVNX, VS1, VS2 and VS3 test series [5,6,13,14]. Analysis of the results, presented in the VS2 report, and subsequent study of VS1 and VS2 data led to three conclusions: One, the flame detection algorithms of the commercial and NRL video systems were too prone to bright nuisance sources like welding, grinding, and cutting torch ($P_{fa} > 20\%$). Two, the smoke detection algorithms of the commercial video systems were more robust than the flame algorithms and less prone to error ($P_{fa} \sim 10\%$). And three, simple combinations of the outputs of the flame and smoke detection algorithms of the video systems did not significantly affect the P_d / P_{fa} ratio. For the VS3 Test Series, algorithm development thus focused on reducing the sensitivity of the Volume Sensor prototype to bright nuisance sources, and the resulting robust nuisance rejection capabilities of the Volume Sensor prototype were clearly demonstrated in the VS3 Test Series [14].

For the VS4 Test Series, algorithm development was directed towards expanding the detection capabilities of the Volume Sensor prototype to include adjacent compartment (hot object) fires and pipe rupture events. Efforts to develop hot object detection algorithms for the LWVD sensor system and DFAM software did not yield a detection algorithm suitable for either system in time for inclusion in the VS4 Test Series. Work in this area is continuing. Efforts to develop pipe rupture detection algorithms, however, were successful and were deployed in the Volume Sensor prototype for the VS4 Test Series. Using data obtained during the VS3 Test Series, a new pipe rupture detection algorithm was developed and incorporated into the ACST sensor system. In addition, a new data fusion pipe rupture algorithm was developed that combined the pipe rupture algorithm of the ACST system with the bright nuisance rejection capabilities of the LWVD and SBVS sensor systems to limit the possibility of false alarms from loud nuisances that were also bright. The ACST sensor system also added two new nuisance detection algorithms for the VS4 Test Series to provide alerts and additional information on nuisances, which have a characteristic acoustic signature, such as welding, grinding, and cutting torch sources. Output from these new algorithms is included in this report for future development. The DFAM software was updated to parse and process data from all of the new ACST algorithms, but the new ACST nuisance algorithm data was not used for data fusion during VS4.

The poor performance of the commercial video systems during the VS3 Test Series prevented a thorough and complete evaluation of the flame, smoke, and nuisance data fusion algorithms. However, some areas of improvement were revealed and small improvements were made to the data fusion algorithms for VS4. First, the logic of the nuisance data fusion algorithm was altered to encompass the compartment as a whole. A nuisance detection from any one of the three sensor suites, for example, a welding alert, blocked VS prototype smoke and flame alarms from the other two, or equivalently, from the compartment. This logic was also employed in the bright nuisance rejection portion of the pipe rupture data fusion algorithm described above. The detection pathways of the flame and smoke data fusion algorithms were not changed from those of VS3, however, the persistence requirements were extended to ten cycles (ten seconds) for both algorithms. The pipe rupture data fusion algorithm also required a ten-cycle persistence. Finally, a simple pre-alarm indication, based on the persistence status, was added to the output of the flame, smoke, and pipe rupture data fusion algorithms for display on the GUI.

All data fusion algorithms were implemented in the Data Fusion Algorithm Module software and processed data internally in the CnC program. During a fire test, data was gathered at one-second intervals from the sensor systems and packaged into a Sensor Gestalt by the CnC software, then passed to the Data Fusion Algorithm Module software where it was parsed into state vectors and analyzed by the nuisance, flame, smoke, and pipe rupture data fusion algorithms. At each interval, the Data Fusion Algorithm Module software returned the current Volume Sensor prototype alarm information to the CnC software for display on the GUI.

4.6.3 Commercial Video Image Fire Detection Systems

Video cameras are used as part of the Volume Sensor prototype, to monitor and record each test, and to provide a live view of the conditions within the compartment during testing. Figures 6 to 8 show photos of the fields of view for each of the three VS suite standard video cameras. The video images were obtained using standard CCD color cameras, Sony SSC-DC393 with Pentex manual iris 3.5 to 8 mm, variable focus lens.

Fig. 6 — Camera view from Volume Sensor prototype location 1

Fig. 7 — Camera view from Volume Sensor prototype location 2

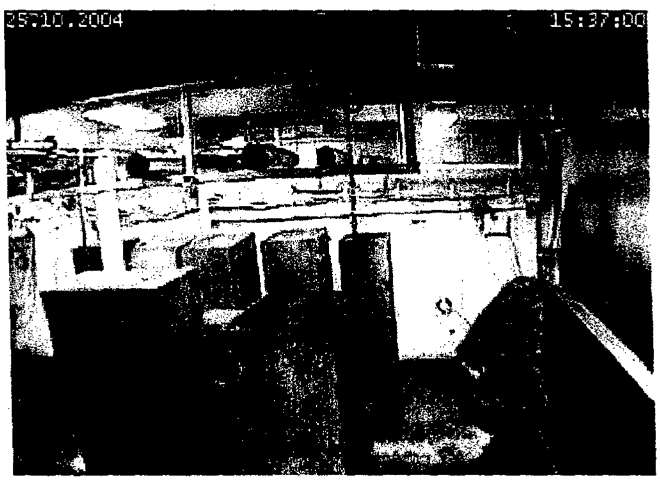

Fig. 8 — Camera view from Volume Sensor prototype location 3

Using a siamese cable (RG59 coax for video together with 18/2 for power), each video image was transmitted to an electronic distribution amplifier, which split the signal to three destinations:

1. SFA video image detection system
2. SigniFire video image detection system
3. Time-date generator

The time-date generator fed into a second electronic distribution amplifier that split the signal to three additional destinations:

4. Fusion Machine 1
5. Fusion Machine 2
6. A digital video recorder

Figure 9 shows an example schematic of how a standard video image signal was split to the various components. The standard video cameras were powered via a 12 VAC supply. The power supply was different than the 12 VDC power supply used in the VS3 test series. Though the cameras are designed to operate on either AC or DC, phasing issues caused the SigniFire system to have difficulties processing the images from DC powered cameras. The cable runs from the cameras to the splitters in the Control Room were direct runs except for one junction box located in node room 5 onboard the ex-USS *Shadwell*. All the cable connections were made with BNC connectors.

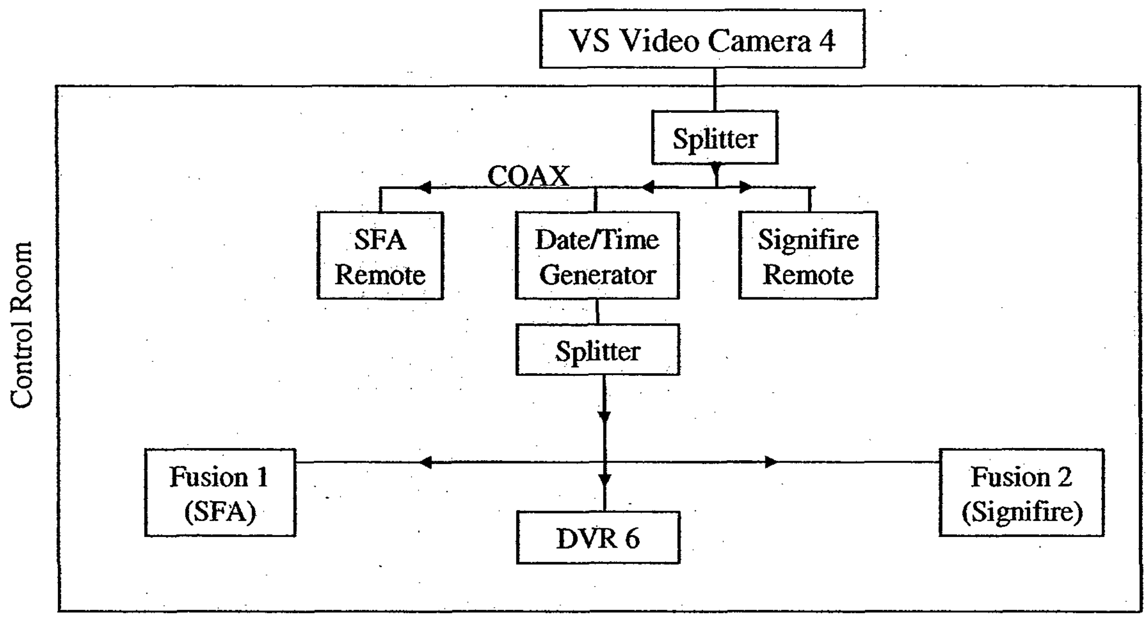

Fig. 9 — Example of standard video image routing diagram

The two commercially available video image fire detection systems were evaluated with the Volume Sensor prototypes. Each system operated from an independent personal computer. The Smoke and Fire Alert (SFA) system was installed on a standard Pentium 4 class PC running Microsoft Windows XP. The SFA VID system was running version 1.1.0.600, which is the same version evaluated in the VS2 test series, except for the software modification that allowed SFA to communicate with the Fusion Machine. SFA version 2.1.5H was used during the VS3 Test Series but was replaced with version 1.1.0.600 because of poor performance. The SFA system utilized both flame and smoke alarm algorithms to detect fires. The manufacturer used the term "Fire" alarm to indicate flame detection. The axonX SigniFire system was installed on a manufacturer supplied PC running Microsoft Windows XP. The axonX system was running SigniFire version 2.2.0.1493. During VS3, SigniFire was running version 2.2.0.1436. This new version did not include any changes to the fire detection algorithms, but did include changes that improved the ability of the SigniFire system to communicate with the Fusion Machine. This system consisted of two flame algorithms and one smoke alarm algorithm. The flame algorithms consisted of one for fires that are directly in the field of view of the camera, and a second "Offsite" algorithm to detect fires outside the field of view. Both of the commercial video image detection (VID) systems used the same cameras incorporated into the VS prototype suites.

Optimal camera settings were determined based on visual observation of the video image as well as by image metrics provided by the VID systems. The cameras were optimized per VID manufacture's recommendations and review during an onsite visit by the manufacturers as testing began. At the beginning of the test series each system was adjusted to establish an optimized image background. For this test series, the SigniFire brightness and contrast settings were adjusted manually by axonX for optimal performance, instead of using the default automatic optimization feature.

As seen in Fig. 9, each video image fire detection system provided a digital output to the fusion system via a local Ethernet network within the control room. Each VID system also maintained an electronic history file of all alarms, including a digital photo (SFA) or movie (SigniFire) showing the video image that caused the alarm condition for each entry. The SFA and SigniFire systems provided, for each historical image or movie respectively, the time and date of the event, the alarm type, camera identification and file name. This allowed for a review of each alarm to ensure that the event was due to fire or smoke and not from an unintended source, such as participants moving around inside the compartment during a test.

4.6.4 Long Wavelength Video Detection (LWVD)

The LWVD system fielded for this test series is described elsewhere [22] and is only described briefly here. The system was composed of a long wavelength camera, an analog to digital video converter and a luminosity-based algorithm. The long wavelength cameras (i.e., CSi-SPECO CVC-130R (0.02 Lux) B&W cameras with a LP720 filter) were co-located with the video cameras as part of a VS sensor suite. The video image was then captured by a video analog-to-digital converter (Pinnacle, Studio Moviebox DV Version 9) and made available to the analysis program as a Microsoft DirectX 9 DirectShow object. The data were processed using the NRL Long Wavelength Video Detection system (LWVD), which operated on the same PCs as the digital video recorders (DVR) that were used to archive the long wavelength video images. Table 8 details the arrangement of cameras, DVRs and LWVD systems. Each long wavelength video image was transmitted from the NIR camera to an electronic distribution amplifier, which split the signal to four destinations:

1. SFA video image detection system
2. SigniFire video image detection system
3. LWVD VIDS
4. Time-date generator

The time-date generator fed into a second electronic distribution amplifier that split the signal to three additional destinations:

5. Fusion Machine 1
6. Fusion Machine 2
7. A digital video recorder

Table 8 — Arrangement of DVR PCs, Cameras and LWVD Systems

DVR	Camera ID	LWVD System	VS sensor suite location
1	NIR 1	LWVD 1	1
2	NIR 2	LWVD 2	2
3	NIR 3	LWVD 3	3
4	Standard 4	---	1
5	Standard 5	---	2
6	Standard 6	---	3

It should be noted that the outputs from the VID systems' analyses of the nightvision cameras were not used in the data fusion algorithms on the FMs. The alarms produced using the nightvision cameras by the VID systems were recorded by the respective VID system history files and FM, for future analysis.

The details of the LWVD algorithm have been discussed elsewhere [7]. The original LWVD software was written in the interpreted, prototype environment of Mathwork's Matlab v6.5 (Release 13) with the Image Acquisition Toolbox extension. For the VS3 Test Series, the program was ported to Microsoft Visual Studio C++ .NET 2003. The C++ version of the LWVD software is functionally equivalent to the original version in terms of the mechanics of data acquisition and algorithmic processing. The C++ version additionally supports communication with the FM using the VSCS protocol.

4.6.5 SBVS Component Prototype

The SBVS Component Prototype is described elsewhere [23] and is only discussed briefly here. Each SBVS Component Prototype was composed of two units, the VIS/IR unit and the UV unit. The VIS/IR unit contained three Si photodiodes (PDs) with interference filters centered at 5900, 7665, and 10500 Å. Two mid-IR (IR) detectors were installed, one at 4.3 μm and one at the 2.7 μm wavelength (2.7 μm + 4.3 μm for sensor suite #3). The data from the second IR detector are not currently used by any algorithm and are recorded for future use and development. The UV units are designed around a standard UV gas discharge tube and electronics (Vibrometer, Inc.). The OmniGuard 860 Optical Flame Detector (Vibrometer, Inc.) used in the SBVS Testbed contained the same UV sensor unit. As outlined in a previous report [10], a distributed-architecture data acquisition system was designed and implemented for the SBVS Component Prototype of the VS Prototype using the FieldPoint line (National Instruments) of data acquisition equipment.

Event detection algorithms for five events were implemented for real-time use. These events are: EVENT, PDSMOKE, FIRE, FIRE_FOV, and WELDING. The EVENT was conceived as a generic trigger, indicating that some, currently unclassifiable event is occurring in the Field-Of-View (FOV) of the sensor. The PDSMOKE event makes use of long-time-scale deviations observed in the 5900 Å channel data that were not correlated with flaming events to detect and classify smoke within the sensor FOV. The algorithms for FIRE and FIRE_FOV detection compare the measured channel data "spectrum," or the pattern of channel values for the five sensors to an empirically determined spectrum for a fully involved flaming fire in the sensor FOV for the FIRE_FOV event, or to a more relaxed spectrum for the FIRE event. An algorithm for the positive detection of one type of nuisance, arc welding was also included. To reduce the algorithm sensitivity to transient signals, a persistence criterion of five seconds was applied to the algorithm outputs. All raw channel data were recorded locally on the SBVS Component data acquisition computer. Baseline-subtracted and normalized sensor channel data and algorithm outputs were forwarded to the Fusion Machines using the VSCS communications protocol. Based on analysis of the VS3 test series data, two changes were made to the SBVS Component Prototype algorithms to improve performance. First, the PDSMOKE algorithm was modified to correctly allow for both positive and negative deviations in the 5900 Å channel data. Also, individual calibrations were implemented for the SBVS hardware in each sensor suite to allow for unit-to-unit variations.

4.6.6 Acoustic System

A microphone was placed at each sensor suite location to measure the acoustic emissions from the pipe ruptures, fires, and nuisance sources. Locations 1 and 2 had Shure MX-393 boundary microphones attached to the bulkhead. For location 1, the microphone was immediately below the camera group, 1.85 m (6.1 ft) up from the deck, and for location 2, the microphone was positioned above the camera group, 44 cm (17 in.) below the overhead. The microphone for location 3 was a Shure MX-202 hanging from an overhead beam in front of the sensor suite, 1 m (3.25 ft) out and 51 cm (20 in.) below the overhead. These microphones have a 50–17,000 Hz frequency range. Two Shure FP-24 conditioning amplifiers, two channels each, powered the microphones and also provided gain adjustment. The acoustic signals were processed using a Prism lunchbox PC, 600 MHz Pentium III, with an internal 16-bit D/A card for data acquisition. The computer program monitoring the microphones was started manually on the lunchbox PC or remotely over the network from an Apple G4 Powerbook. Once started, all control passed to the Fusion Machines, which started and stopped the actual processing through XML command messages. All acoustic data were stored to disk files according to FM2's start and stop commands. Processing of the data was done in real-time, and the status of the criteria was provided in XML state vector messages to the data fusion systems via the fiber optic Gigabit network. In addition, a fourth microphone was added to the compartment so sound could be heard in the control room. The fourth microphone was not used by the Fusion Machines, but was rather used for observations of sounds occurring in the compartment.

The acoustic system provided three algorithms to detect relevant acoustic events; they were Pipe Rupture, HF Nuisance, and Grinding. The first one of these generated an alarm for water events while the second and third generated nuisance alerts on events that should not trigger alarms. The HF Nuisance algorithm was intended to trigger on arc welding and cutting torch activities while the Grinding was intended to detect grinding events. All of these algorithms operated independently in that they did not consider the responses of the other two. They each functioned similarly in that each one looked at a specific band of the acoustic spectrum. When the level in the band rose sufficiently above the background a pre-event state was set. If the level remained elevated for a set time, then certain criteria were examined and, if met, the alarm level was increased above 0. If the criteria were then met for a sufficient additional time the alarm level reached 1 and an alarm was formally declared by the ACST system. The current state of the ACST system was fully available to the Fusion Machines at all times, since both channel data and alarm data for all algorithms were sent, when requested through a START command. The basic background averaging time was 3 minutes as calculated using exponential averaging and all algorithms required the level to remain elevated for 20 seconds before the criteria were examined and an additional 10 seconds before an alarm or alert condition could be raised to 1. Both the Pipe Rupture and HF Nuisance algorithms looked at the spectrum from 7 - 16 kHz, and required the level to exceed 12 dB above the background. The Pipe Rupture algorithm used the criteria that the level was elevated above 12 dB, that the level did not fluctuate significantly with time, i. e., a small standard deviation, and that the spectrum was nearly linear over the frequency band. The HF Nuisance algorithm used the opposite of the latter two criteria that the level was fluctuating in time and was non-linear over the band. Thus, it was not possible for a Pipe Rupture alarm and an HF Nuisance alert to be generated at the same time. The Grinding algorithm used a 6 dB threshold in the frequency band 500 – 3000 Hz, and the same criteria as the HF Nuisance algorithm. The principal criteria in setting these thresholds was that only the Pipe Rupture algorithm should trigger on the water events and not the HF Nuisance or Grinding algorithms.

4.6.7 Shipboard Setup

Because of the experimental nature of this program, there were twelve computers used, as itemized below:

1. SFA Field Unit
2. SigniFire Field Unit
3. Fusion Machine 1
4. Fusion Machine 2
5. Acoustic system (located in 3-23-2, remote monitor in control room)
6. SBVS system (DAQ unit in test space)
7. VS Nightvision Camera 1/DVR 1/LWVD 1
8. VS Nightvision Camera 2/DVR 2/LWVD 2
9. VS Nightvision Camera 3/DVR 3/LWVD 3
10. VS Video Camera 4/DVR 4
11. VS Video Camera 5/DVR 5
12. VS Video Camera 6/DVR 6

The majority of the systems were located in the control room, including the six DVRs, the two FMs, the two VID systems, the remote acoustic monitor system, and the SBVS processing system. The FieldPoint unit for the SBVS system was located in the test compartment and the acoustic processing lunchbox PC was located in the space adjacent to the test compartment.

4.7 Instrumentation

In addition to the Volume Sensor prototype suites, instrumentation (see Table 7) was installed throughout the test compartment to measure temperatures and smoke density (visibility). The measurements were not directly utilized by the Volume Sensor prototypes; however, they provided general space conditions and benchmarks for typical, commercial spot-type fire detection systems. Details on the instrumentation used for these measurements are discussed in Sections 4.7.1 through 4.7.3. The locations of the instrumentation are shown in Figs. 10, 11, and 12.

4.7.1 Optical Density Meters

Smoke obscuration, which provides a measurement of visibility, was measured using Optical Density Meters (ODMs). The ODMs used an 880 nm infrared (IR) light emitting diode (IRLED) and receptor arrangement over a 1.0 m (3.3 ft) path length. The ODMs were positioned adjacent to each grouping of smoke detectors within the compartment. One ODM was positioned in the center of the space at a height of 1.5 m (5 ft) above the deck. White light ODMs were also mounted at two locations, Bay 4 starboard and Bay 2 port adjacent to the spot-type detector clusters, see Fig 10. The laboratory tests conducted in this program [2,13] have used white light, low-voltage spot lamps (GE 4515) spaced 1.5 m (5.0 ft) from barrier layer photovoltaic cells (Hyugen 856-RR) for ODMs. The inclusion of both types of ODMs provided additional information for comparing smoke measurement techniques for a range of smoke sources.

4.7.2 Thermocouples

The overhead air temperatures adjacent to the detectors were measured using 1.59 mm (0.0625 in.) Type K Inconel sheathed thermocouples. The thermocouples were positioned at the approximate height of the detector heads, 10 cm (4 inches) below the overhead. The forward bulkhead of the test space was instrumented with thermocouples to map the steel temperature during the painted bulkhead heating scenario. The thermocouple locations were the same as those used in the previous magazine testing [4] and are detailed in Fig. 11.

Two thermocouple trees were used to measure compartment air temperatures. Each tree consisted of three Inconel-sheathed, type K thermocouples positioned 0.30 m (1.0 ft), 1.5 m (5.0 ft), and 2.7 m (9.0 ft) above the deck. Thermocouple tree positions are given in Table 9.

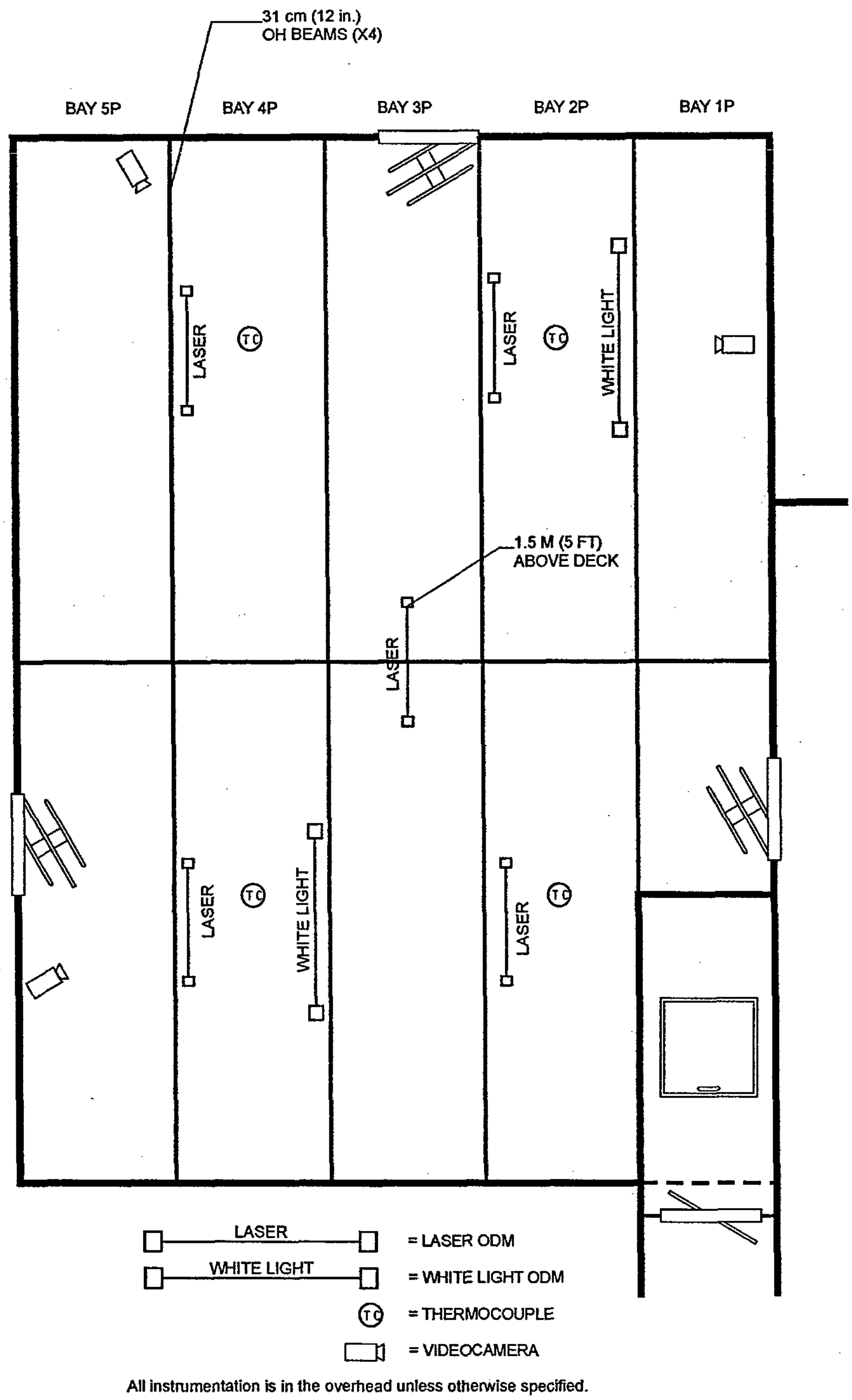

Fig. 10 — Layout of ODMs in test compartment

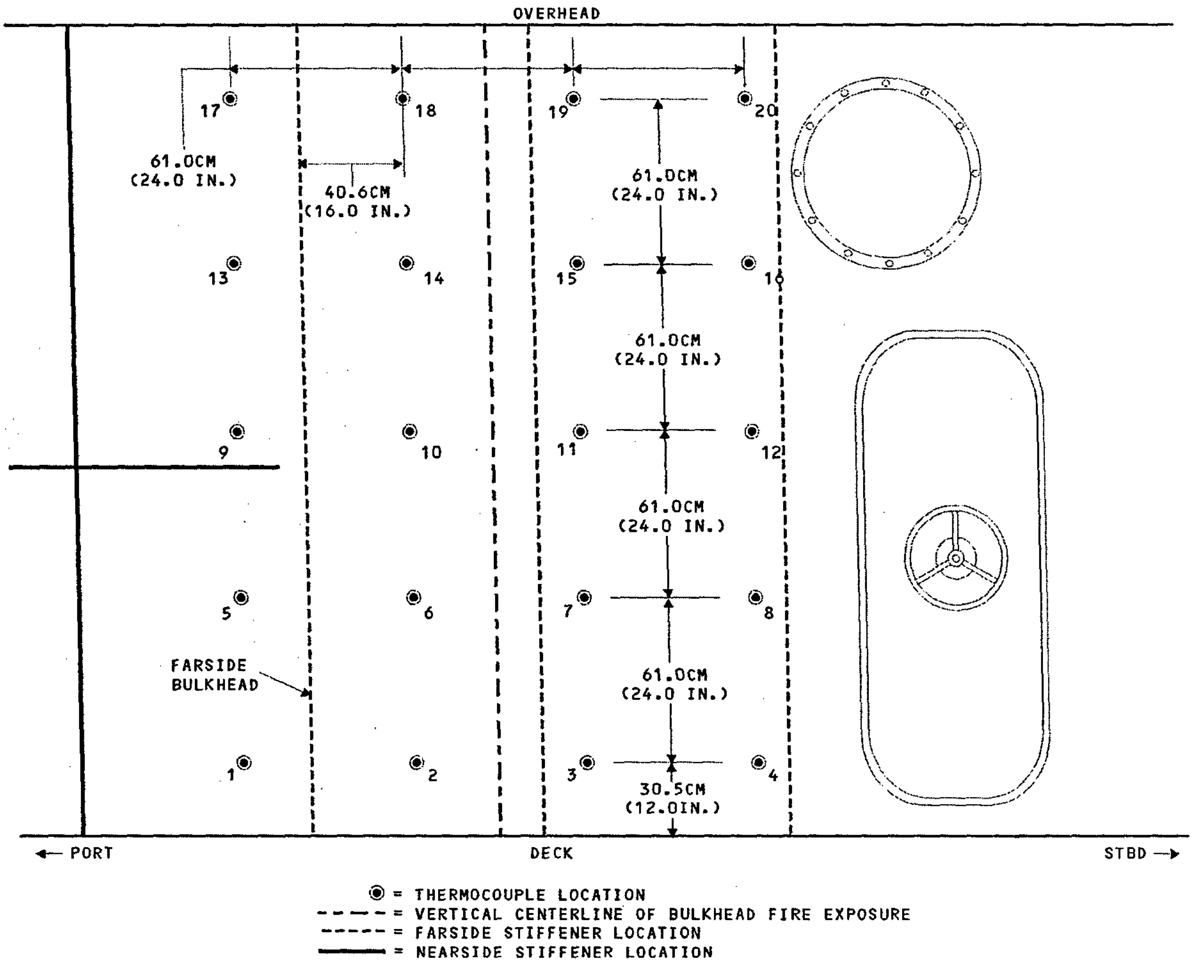

Fig. 11 — Locations of forward bulkhead thermocouples

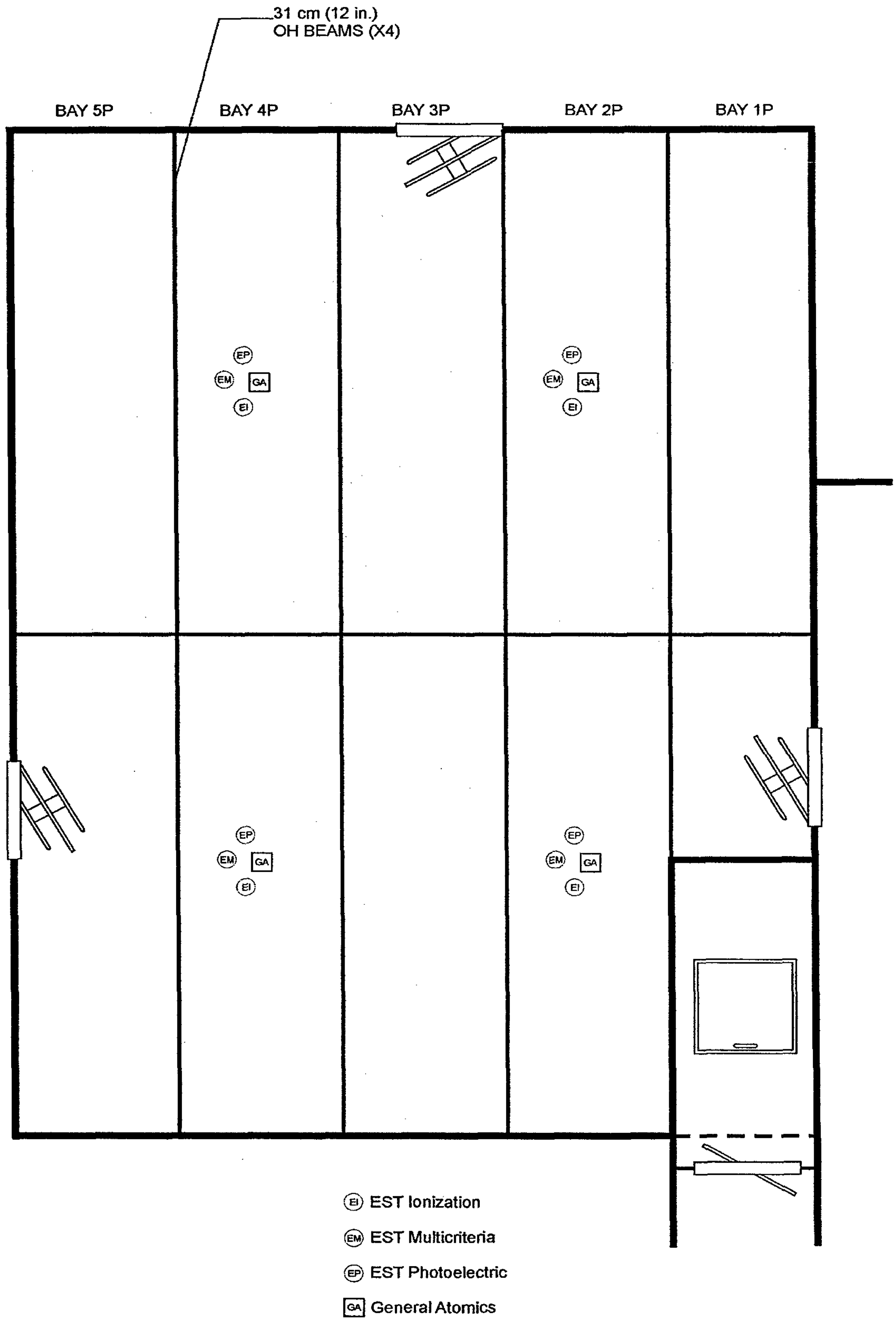

Fig. 12 — Locations of spot-type detectors in test compartment

Table 9 — Position of Thermocouple Trees in the 3rd Deck Magazine

Centerline Position[1] (m (ft))	Athwartship Position[1] (m (ft))
3.0 (9.7)	1.9 (6.1)
3.0 (9.7)	5.9 (19.3)

[1]Measured from the aft, starboard corner of the space

4.7.3 Detectors

The prototype FM results were compared to commercially available smoke detection systems as outlined in Ref. [13]. Four COTS EST spot-type ionization, photoelectric, and multicriteria detection systems were installed in clusters as shown in Fig. 12. The ion, photo, and multicriteria detector systems were used as the primary benchmark for assessing the performance of the VS prototype. All similar spot-type detectors were considered part of a system for the entire test compartment. For instance, if any of the four EST ionization detectors installed in the test space alarmed, then the EST ion system was considered to have alarmed. The EST detectors were re-initialized before each test using a computer software program provided by EST and installed on a laptop located in the compartment adjacent to the test compartment.

4.8 Test Procedure

The general test procedure was to assure that all equipment was operational and that all system clocks were synchronized. The test was then conducted. Once the testing was complete, the compartment was ventilated and the next test begun. The procedure included an overall system check and establishment of a clean baseline for all systems between tests. The EST detectors were re-initialized before each test using a computer software program provided by EST. For each test, the various systems were started and allowed to collect background data for a minimum of 240 seconds. After the background data were collected, the source was initiated and allowed to continue until fully consumed or until all systems were in alarm or showed no change in detection due to quasi-steady state conditions. Times for source initiation, DAQ start, DAQ stop, source termination, and source transition are provided in Table 10 for each test.

4.9 Test Matrix

Table 10 presents the test summary of all tests conducted for this test series. One hundred tests were conducted over a nine-day period. The tests conducted were designed to provide a range of sources and source locations to comprehensively evaluate the Fusion Machines with challenging shipboard scenarios. The matrix repeated many of the tests conducted in the VS3 test series for comparison purposes. Besides the fire, nuisance, pipe rupture and gas release sources, additional events were conducted to provide an expanded scenario database for future algorithm development.

Table 10 — Test Summary for VS4 Test Series Conducted Onboard the ex-USS *Shadwell*

Test	Brief Source Description	Source Type	Source Location	Ventilation	Date	Event Times (hh:mm:ss)				
						DAQ Start	Source Initiation	Source Transition	Source Terminated	Stop DAQ
VS4-001	Flaming Card board Boxes with Polystyrene pellets	Flaming	2	On	10/18/2004	13:32:00	13:36:18		13:45:00	13:46:00
VS4-002	Welding	Nuisance	4	On	10/18/2004	14:34:01	14:38:02		14:45:05	14:46:00
VS4-003	Smoldering Mattress and Bedding	Smoldering	2	On	10/18/2004	15:43:30	15:47:30	16:11:50	16:12:26	16:13:09
VS4-004	VHF Radio/People working	Nuisance	5, 4, 2	On	10/18/2004	16:37:00	16:41:01		16:42:15	16:42:30
VS4-005	Torch Cut Steel	Nuisance	4	On	10/19/2004	8:40:00	8:44:02		8:50:05	8:50:30
VS4-006	Flaming Trash Can	Flaming	2	On	10/19/2004	9:35:01	9:39:03		9:46:38	9:47:00
VS4-007	Smoldering Cable Bundle	Smoldering	2	On	10/19/2004	10:25:01	10:29:02	11:04:30	11:08:59	11:09:30
VS4-008	Welding (140 A)	Nuisance	4	On	10/19/2004	12:19:00	12:23:02		12:27:55	12:28:30
VS4-009	Flaming Shipping Supplies	Flaming	2	On	10/19/2004	13:00:01	13:05:36		13:25:18	13:26:00
VS4-010	Waving materials	Nuisance	5, 4, 3, 5	On	10/19/2004	13:48:01	13:52:00		14:02:00	14:02:00
VS4-011	Smoldering Laundry	Smoldering	2	On	10/19/2004	14:10:01	14:14:04		14:24:28	14:25:00
VS4-012	Spilling Metal Bolts	Nuisance	4, 1	On	10/19/2004	15:02:00	15:06:07		15:14:35	15:15:30
VS4-013	AM/FM Radio/Cassette player	Nuisance	4, 1	On	10/19/2004	15:19:00	15:23:00		15:31:18	15:32:00
VS4-014	Grinding Painted Steel	Nuisance	4	On	10/19/2004	15:38:00	15:42:05		15:50:03	15:51:00
VS4-015	Flaming IPA Spill Fire/Trash bag	Flaming	2	On	10/19/2004	16:04:00	16:08:04		16:10:51	16:11:30
VS4-016	Engine Exhaust	Nuisance	Inside WTD 3-29-1	On	10/20/2004	8:32:00	8:36:00		8:45:00	8:46:00
VS4-017	Smoldering Oily Rags	Smoldering	2	On	10/20/2004	9:13:00	9:17:00		9:42:53	9:44:00
VS4-018	Flaming Cardboard Boxes with Polystyrene pellets	Flaming	3	On	10/20/2004	10:24:00	10:28:00		10:33:40	10:34:30
VS4-019	TV/People working in space	Nuisance	4 facing fwd	On	10/20/2004	11:09:01	11:03:02		11:17:55	11:18:30
VS4-020	TV with video	Nuisance	4 facing fwd	On	10/20/2004	11:37:02	11:41:05		11:50:29	11:51:03

Table 10 — Test Summary for VS4 Test Series Conducted Onboard the ex-USS *Shadwell* (Continued)

Test	Brief Source Description	Source Type	Source Location	Ventilation	Date	Event Times (hh:mm:ss)				
						DAQ Start	Source Initiation	Source Transition	Source Terminated	Stop DAQ
VS4-021	Smoldering Mattress and Bedding	Smoldering	3	On	10/20/2004	11:57:01	12:01:00	12:20:40	12:23:14	12:23:30
VS4-022	Flaming Trash Can	Flaming	3	On	10/20/2004	13:15:01	13:19:04		13:33:47	13:34:30
VS4-023	Smoldering Cable Bundle	Smoldering	3 OH	On	10/20/2004	14:02:01	14:06:02		14:38:10	14:39:00
VS4-024	Normal Toasting	Nuisance	4	Off	10/20/2004	15:17:00	15:21:01		15:31:30	15:32:30
VS4-025	Torch Cut Steel	Nuisance	3	On	10/20/2004	15:53:31	15:57:32		16:03:16	16:05:00
VS4-026	Flaming Cardboard Boxes with Polystyrene pellets	Flaming	5	On	10/20/2004	16:30:01	16:34:03		16:43:00	16:43:00
VS4-027	Flaming Shipping Supplies	Flaming	3	On	10/21/2004	8:26:00	8:47:58		9:12:34	9:13:00
VS4-028	Pipe rupture - 1 m above deck, 40 psi	Pipe rupture	9	On	10/21/2004	9:48:00	9:52:00		9:55:00	9:55:00
VS4-029	People working in space - clean up pipe rupture	Nuisance	9	On	10/21/2004	10:03:03	10:07:00		10:15:00	10:15:00
VS4-030	Smoldering Laundry	Smoldering	3	On	10/21/2004	10:18:00	10:22:05	10:35:10	10:38:00	10:39:30
VS4-031	Pipe rupture - gash 10" x 0.125", 40 psi	Pipe rupture	9	On	10/21/2004	11:02:00	11:11:02		11:14:00	11:15:00
VS4-032	Flaming IPA Spill Fire/ Trash Bag	Flaming	3	On	10/21/2004	11:25:01	11:29:10		11:34:58	11:35:30
VS4-033	Smoldering Oily Rags	Smoldering	3	On	10/21/2004	12:34:01	12:37:50		12:53:00	12:54:00
VS4-034	Heat gun/space heater/fan	Nuisance	5, 4, 1	Off	10/21/2004	13:27:02	13:31:03		13:45:55	13:47:00
VS4-035	Grinding Painted Steel	Nuisance	3	On	10/21/2004	13:53:00	13:57:05		14:03:08	14:04:00
VS4-036	Smoldering Mattress and Bedding	Smoldering	5	On	10/21/2004	14:21:00	14:25:01	14:42:00	14:46:00	14:45:30
VS4-037	Pipe rupture - sprinkler nozzle, 1 m above deck	Pipe rupture	9	On	10/21/2004	15:00:00	15:04:00		15:08:30	15:08:30
VS4-038	Flaming Trash Can	Flaming	5	On	10/21/2004	15:50:00	15:54:02		16:01:00	16:02:02
VS4-039	Smoldering Cable Bundle	Smoldering	5 OH	On	10/21/2004	16:26:00	16:30:07		17:05:10	17:06:00

Table 10 — Test Summary for VS4 Test Series Conducted Onboard the ex-USS *Shadwell* (Continued)

Test	Brief Source Description	Source Type	Source Location	Ventilation	Date	Event Times (hh:mm:ss)				
						DAQ Start	Source Initiation	Source Transition	Source Terminated	Stop DAQ
VS4-040	N2 release, Air line nozzle	Gas release	Stbd Blkhd, on deck	On	10/22/2004	8:14:00	8:18:05		8:30:04	8:31:00
VS4-041	Smoldering Laundry	Smoldering	5	On	10/22/2004	8:47:02	8:51:05		8:59:26	9:00:00
VS4-042	N2 release - 0.25 in. dia	Gas release	4 OH	On	10/22/2004	9:14:02	9:18:01		9:25:00	9:26:00
VS4-043	Flaming Shipping Supplies	Flaming	5	On	10/22/2004	9:34:00	9:38:30		10:15:00	10:16:00
VS4-044	Flaming IPA Spill Fire/ Trash Bag	Flaming	5	On	10/22/2004	10:38:00	10:47:30		10:54:07	10:55:00
VS4-045	Pipe rupture - gash 10" x 0.125", 40 psi	Pipe rupture	5	On	10/22/2004	11:11:00	11:15:01		11:17:01	11:18:30
VS4-046	Smoldering Oily Rags	Smoldering	5	On	10/22/2004	11:30:00	11:34:02		11:55:24	11:56:00
VS4-047	N2 release - 0.25 and 1/16 in. dia	Gas release	4 OH	Off	10/22/2004	13:00:02	13:04:01		13:21:01	13:21:32
VS4-048	Painted bulkhead heating	Smoldering	6	On	10/22/2004	13:53:02	13:57:23		14:12:15	14:13:01
VS4-049	Pipe rupture - gash 10" x 0.125", 40 psi	Pipe rupture	5	On	10/25/2004	8:14:02	8:18:00		8:23:10	8:24:30
VS4-050	Flaming Shipping Supplies	Flaming	4	On	10/25/2004	8:45:00	8:49:03		9:10:23	9:11:00
VS4-051	Pipe rupture - gash 10" x 0.125", 40 psi	Pipe rupture	4	On	10/25/2004	9:37:01	9:41:01		9:44:33	9:45:00
VS4-052	People working in space - clean up pipe rupture	Nuisance	4	On	10/25/2004	9:50:02	9:50:10		10:00:00	10:00:00
VS4-053	Flaming IPA Spill Fire/Trash Bag	Flaming	4	On	10/25/2004	10:06:02	10:19:09		10:25:01	10:26:00
VS4-054	Pipe rupture – 1 m above deck, 40 psi	Pipe rupture	4	On	10/25/2004	10:40:02	10:44:01		10:48:23	10:50:30
VS4-055	People working in space - clean up pipe rupture	Nuisance	4	On	10/25/2004	10:53:00	10:57:06		11:08:00	11:08:00
VS4-056	Grinding Painted Steel	Nuisance	4	On	10/25/2004	11:14:00	11:18:01		11:26:01	11:27:30
VS4-057	Pipe rupture - sprinkler nozzle, 1 m above deck	Pipe rupture	4	On	10/25/2004	12:20:00	12:24:00		12:27:57	12:29:00

Table 10 — Test Summary for VS4 Test Series Conducted Onboard the ex-USS *Shadwell* (Continued)

Test	Brief Source Description	Source Type	Source Location	Ventilation	Date	Event Times (hh:mm:ss)				
						DAQ Start	Source Initiation	Source Transition	Source Terminated	Stop DAQ
VS4-058	Flaming Cardboard Boxes with Polystyrene pellets	Flaming	7	On	10/25/2004	12:44:00	12:48:00		12:57:40	12:58:00
VS4-059	Air release, SCBA discharge	Gas release	4	On	10/25/2004	13:26:00	13:30:00		13:31:45	13:32:30
VS4-060	Pipe rupture - water mist nozzle, 1 m above deck	Pipe rupture	4	On	10/25/2004	13:40:00	13:44:00		13:49:00	13:49:30
VS4-061	Smoldering Cable Bundle	Smoldering	3 on deck	On	10/25/2004	14:02:00	14:06:02		14:51:05	14:52:00
VS4-062	Pipe rupture - gash 10" x 0.125", 40 psi	Pipe rupture	4	On	10/25/2004	15:31:00	15:35:00		15:37:00	15:37:30
VS4-063	Painted bulkhead heating	Smoldering	6	On	10/25/2004	15:57:02	16:03:05		16:17:00	16:18:30
VS4-064	Engine Exhaust	Nuisance	Inside WTD 3-29-1	On	10/26/2004	8:32:00	8:36:22		8:45:00	8:46:00
VS4-065	Pipe rupture – gash 10" x 0.125", 40 psi against boxes	Pipe rupture	4	On	10/26/2004	9:00:00	9:04:00		9:06:00	9:06:30
VS4-066	Aerosol	Nuisance	4	Off	10/26/2004	9:24:00	9:28:15		9:30:20	9:31:00
VS4-067	Flash Photography	Nuisance	2, 1 and 3	On	10/26/2004	9:44:00	9:48:00		9:55:06	9:55:30
VS4-068	Flaming IPA Spill Fire/ Trash Bag	Flaming	2	On	10/26/2004	10:01:00	10:05:07		10:14:00	10:14:30
VS4-069	Smoldering Cable Bundle	Smoldering	7	On	10/26/2004	10:39:00	10:43:01	11:08:00	11:12:48	11:13:30
VS4-070	Flaming Cardboard Boxes with Polystyrene pellets	Flaming	7	On	10/26/2004	12:08:00	12:12:05		12:20:00	12:20:30
VS4-071	Pipe rupture – gash 10" x 0.125", 40 psi against mattress	Pipe rupture	4	On	10/26/2004	12:49:00	12:53:00		12:55:00	12:59:00
VS4-072	Pipe rupture – gash 10" x 0.125", 40 psi against mattress	Pipe rupture	4	On	10/26/2004	13:04:00	13:08:00		13:10:00	13:11:00
VS4-073	Change of lighting – Lights on to lights off	Developmental	Entire space	On	10/26/2004	13:28:00	13:32:00		13:34:00	12:34:00

Table 10 — Test Summary for VS4 Test Series Conducted Onboard the ex-USS *Shadwell* (Continued)

Test	Brief Source Description	Source Type	Source Location	Ventilation	Date	Event Times (hh:mm:ss)				
						DAQ Start	Source Initiation	Source Transition	Source Terminated	Stop DAQ
VS4-074	Change of lighting – Lights off to lights on	Developmental	Entire space	On	10/26/2004	13:38:00	13:42:08		13:44:00	13:44:00
VS4-075	Flaming Trash Can with Lights Off	Developmental	2	On	10/26/2004	13:54:00	13:58:38		14:08:00	14:08:00
VS4-076	Flaming Cardboard Boxes with Lights Off	Developmental	2	On high	10/26/2004	14:31:00	14:35:50		14:42:00	14:42:40
VS4-077	Grinding Painted Steel	Nuisance	4	On	10/26/2004	15:10:00	15:14:04		15:19:57	15:20:30
VS4-078	Painted bulkhead heating	Smoldering	6	On	10/26/2004	15:57:01	16:01:16		16:17:17	16:21:00
VS4-079	Pipe rupture – sprinkler nozzle, 1 m above deck	Pipe rupture	9	On	10/27/2004	8:01:00	8:05:01		8:07:00	8:08:00
VS4-080	Change of lighting with Flaming Trash Can (lights on, then off prior to ignition)	Developmental	2	On	10/27/2004	8:21:01	8:26:14		8:38:04	8:38:30
VS4-081	Flash Photography with four people	Nuisance	1 and 4	On	10/27/2004	9:11:00	9:15:23		9:19:04	9:15:30
VS4-082	Flaming Cardboard Boxes with Polystyrene pellets	Flaming	7	On	10/27/2004	9:25:00	9:29:02		9:36:40	9:38:30
VS4-083	Welding	Nuisance	5	On	10/27/2004	10:06:00	10:10:03		10:13:15	10:14:00
VS4-084	Smoldering Cable Bundle	Smoldering	3 on deck	Off	10/27/2004	10:30:00	10:34:07	11:00:55	11:05:50	11:06:00
VS4-085	Grinding Painted Steel	Nuisance	5	On	10/27/2004	12:17:00	12:21:00		12:29:00	12:29:30
VS4-086	Smoldering Oily Rags	Smoldering	4	On	10/27/2004	12:36:00	12:40:00	12:40:00	12:53:18	12:55:20
VS4-087	Pipe rupture - gash 10" x 0.125", 40 psi	Pipe rupture	9	On	10/27/2004	13:25:00	13:29:01		13:31:01	13:32:00
VS4-088	Change of lighting with flaming cardboard boxes (lights on, then off prior to ignition)	Developmental	2	On	10/27/2004	14:20:00	14:25:00		14:32:08	14:33:00
VS4-089	Torch Cut Steel	Nuisance	5	On	10/27/2004	14:59:00	15:03:02		15:09:10	15:09:30

Table 10 — Test Summary for VS4 Test Series Conducted Onboard the ex-USS *Shadwell* (Continued)

Test	Brief Source Description	Source Type	Source Location	Ventilation	Date	Event Times (hh:mm:ss)				
						DAQ Start	Source Initiation	Source Transition	Source Terminated	Stop DAQ
VS4-090	Welding preceded by no, normal and high ventilation	Nuisance	3	On	10/27/2004	15:24:00	15:36:03		15:40:52	15:42:00
VS4-091	Hot metal surface – Shielded IPA spill fire	flaming	port of 4	On	10/27/2004	16:02:00	16:06:06		16:17:14	16:18:00
VS4-092	Tig welding stainless steel	Nuisance	4	On	10/27/2004	16:34:00	16:38:00		16:42:00	16:42:30
VS4-093	Pipe rupture - Bete P80 nozzle orifice, 44-149 psi	Pipe rupture	9	Off	10/28/2004	8:07:00	8:25:00		8:30:00	8:30:00
VS4-094	Smoldering Laundry	Smoldering	4	On	10/28/2004	8:53:00	8:57		9:07:19	5:08:00
VS4-095	Smoldering laundry - Camera 4 tilted up	Smoldering	4	On	10/28/2004	9:36:00	9:40:01		9:50:30	9:50:30
VS4-096	Flaming trash can - Camera 4 tilted up so light in F.O.V[1]	Flaming	3	On	10/28/2004	10:43:00	10:47:02		10:53:00	10:54:00
VS4-097	Smoldering laundry - Camera 4 tilted up so light in F.O.V[1]	Smoldering	4	On	10/28/2004	12:16:00	12:16:00		12:20:08	12:30:26
VS4-098	Space heater	Nuisance	4	On	10/28/2004	12:42:02	12:46:00		12:55:56	12:56:00
VS4-099	Toaster	Nuisance	7	On	10/28/2004	13:01:00	13:05:05		13:08:25	13:10:00
VS4-100	Space heater	Nuisance	8	On	10/28/2004	13:13:00	13:17:01		13:23:00	13:23:00

[1]F.O.V. = Field of View

5.0 RESULTS

The following measures of performance were used to evaluate the Volume Sensor prototypes and the component sensor systems:

1. General functionality of the multi-component prototype system (i.e., successful integration of components and meeting design objectives of the command and control (CnC) and GUI software)
2. Percent correct classification of fire, nuisance and pipe rupture sources
3. Speed of response to fire sources

The performance of the Volume Sensor prototype was compared to the COTS spot-type ionization and photoelectric smoke detectors as well as the COTS VID systems.

Response and alarm times of the Volume Sensor components, and therefore the overall VS prototype, are due to pipe ruptures, smoke, flame, the transitioning of a smoldering source to a flaming source, or nuisance sources. In some cases, the cause of an alarm may be due to other factors than the source being tested such as a person in the compartment. General observations during the test series and a review of the recorded alarm times indicate that the majority of alarms were caused by the intended source and were not fortuitous or inadvertent alarms. The video and image history files recorded by the VID systems were reviewed for alarms that were inadvertently activated by events other than those being tested. These alarms are noted in the text. The Fusion Machine alarms, and alarms reported to the Fusion Machines (i.e., listed in the Tables) have been reviewed for misclassifications, all of which are documented in the text below.

5.1 General Functionality of Volume Sensor Prototype System

The XML-based communications protocol for transmitting command and data packets between Volume Sensor components over the ship's TCP/IP network continued to work very well. Alarm times and scaled data from the sensor systems were reliably and accurately transmitted to the Fusion Machines.

The current test series provided a wealth of high-quality data for future algorithm development and improvements to the sensor systems and the Data Fusion Algorithm Module. The NRL-designed SBVS, LWVD, and ACST sensor systems recorded raw and scaled sensor data from all tests. The Fusion Machines created redundant logs of all data packets received from the sensor systems, including the commercial video systems. In addition, the Data Fusion Algorithm Module generated and recorded a complete set of state vectors from all the Volume Sensor components for the test series. All video from the cameras used was recorded digitally.

Alarm times and response times from all Volume Sensor components for the current test series are listed in the tables of the next three sections. These tables break down the test series into flaming fire, smoldering fire, nuisance, and pipe rupture-type events. Note that pipe rupture tests were conducted with water pooling in areas on the deck, however, water never accumulated to cover the entire deck area of the compartment space.

5.2 Volume Sensor Prototypes

Alarm times, response times, and alarm types obtained by Fusion Machine 1 (FM1) and Fusion Machine 2 (FM2) for the two Volume Sensor prototypes are documented in this section. The Fusion Machines received identical data from the SBVS, LWVD, and ACST sensor systems. Fusion Machine 1 employed the Fastcom Smoke and Fire Alert (SFA) commercial video image detection system, while Fusion Machine 2 used the axonX SigniFire video detection system. The test series is separated into flaming, smoldering, nuisance, and pipe rupture events. Between test series VS3 and VS4, the pipe rupture category was added to the data fusion algorithms employed by the Volume Sensor prototypes. Table 11 lists the results for flaming fire events, Table 12 lists the results for smoldering fire events, Table 13 lists the results for nuisance source events, and Table 14 lists the results for the pipe rupture events. The words flaming, smoldering, and nuisance have been excised from the test descriptions for brevity.

The format for Tables 11 to 14 is nearly identical. The first two columns give the test number and test description. For Tables 11 and 14, columns 3, 4, and 5 list the alarm times, the response times, and the alarm types, respectively, for Fusion Machine 1. Similarly, columns 6, 7, and 8 list the alarm times, the response times, and the alarm types, respectively, for Fusion Machine 2. The alarm times are provided in hh:mm:ss format, the response times in seconds after the source initiation time, and the alarm types indicate which data fusion algorithm generated the alarm: flame (F), smoke (S), or pipe rupture (P). For all tables, a listed alarm time is always the first alarm time observed for that machine. An entry of "DNA" indicates the event was not detected. Note that for several tests, the data fusion smoke and flame algorithms both generated alarm times.

Table 11 documents the response of the Fusion Machines in tests with flaming fire sources. Both Fusion Machines correctly detected every flaming fire source. Examination of columns 5 and 8 in Table 11 shows that the data fusion flame algorithm was responsible for the first alarm in approximately half of the 20 alarms produced by the Fusion Machines for flaming fires, with the remainder of the flaming fire alarms produced by the data fusion smoke algorithm. For the flaming fire alarms, responses from a combination of the SBVS and LWVD systems were responsible for approximately 95% of the detections. A combination of the SBVS and commercial VID flame detections were responsible for the other 5% of flaming fire alarms. The data fusion smoke algorithm produced the rest of the Fusion Machine alarms for the flaming fires. The commercial VID system smoke detection algorithms triggered approximately 90% of these alarms, with the other 10% due to the SBVS smoke detection algorithm. For FM1, the average response time was 158 seconds with a standard deviation of 222 and median of 126 seconds. For FM2, the average response time was 207 seconds with a standard deviation of 260 and median of 133 seconds.

Table 11 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types for Flaming Source Events Detected by the two Volume Sensor Prototypes, FM1 and FM2

Test ID	Source Description	FM1			FM2		
		Alarm	Response	Type	Alarm	Response	Type
VS4-001	Cardboard Boxes with Polystyrene pellets	13:39:03	165	S	13:39:12	174	S
VS4-018	Cardboard Boxes with Polystyrene pellets	10:29:43	103	S	10:29:45	105	S
VS4-026	Cardboard Boxes with Polystyrene pellets	16:37:03	180	F	16:37:03	180	F
VS4-058	Cardboard Boxes with Polystyrene pellets	12:50:20	140	S	12:50:34	154	F
VS4-070	Cardboard Boxes with Polystyrene pellets	12:15:39	214	S	12:15:15	190	S
VS4-082	Cardboard Boxes with Polystyrene pellets	9:31:13	131	S	9:31:16	134	S
VS4-091	Hot metal surface – Shielded IPA spill fire	16:06:23	17	F	16:06:23	17	F
VS4-015	IPA Spill Fire/Trash bag	16:08:24	20	F	16:08:24	20	F
VS4-032	IPA Spill Fire/Trash Bag	11:29:28	18	F	11:29:29	19	F
VS4-044	IPA Spill Fire/Trash Bag	10:47:48	18	F	10:47:48	18	F
VS4-053	IPA Spill Fire/Trash Bag	10:19:34	25	F	10:19:33	24	F
VS4-068	IPA Spill Fire/Trash Bag	10:05:32	25	F	10:05:30	23	F
VS4-009	Shipping Supplies	13:07:37	121	S	13:07:48	132	S
VS4-027	Shipping Supplies	8:48:39	41	S	8:59:19	681	F
VS4-043	Shipping Supplies	9:55:43	1033	S	9:55:03	993	S
VS4-050	Shipping Supplies	8:51:21	138	S	8:52:12	189	F
VS4-006	Trash Can	9:40:33	90	F	9:40:33	90	F
VS4-022	Trash Can	13:24:09	305	S	13:29:41	637	S
VS4-038	Trash Can	15:56:20	138	F	15:56:05	123	F
VS4-096	Trash Can - Camera 4 tilted up	10:51:01	239	S	10:51:07	245	S

The Fusion Machine response to smoldering fire events is recorded in Table 12. Note that test ID's marked with a "*" denote tests where the smoldering material transitioned to flaming material. Again, both Fusion Machines correctly detected all smoldering fire events. Approximately 90% of the Fusion Machine smoke alarms listed in Table 12 were triggered by the commercial VID system smoke detection algorithms through the data fusion smoke algorithm. The SBVS smoke detection algorithm triggered the other 10% of the alarms. The data fusion flame algorithm was responsible for one alarm, FM2 for test VS4-036, triggered by the combination of SBVS and LWVD flame detections after the test had transitioned to a flaming fire. As discussed further below, the commercial VID systems performance was much improved compared to the previous test series (VS3) and definitely enhanced the performance of the Fusion Machines for smoldering fires. Note also that the data fusion flame algorithm detected several of the transitioning tests subsequent to their initial detection via the data fusion smoke algorithm. For FM1, the average response time was 500 seconds with a standard deviation of 456 and median of 393 seconds. For FM2, the average response time was significantly slower at 709 seconds with a standard deviation of 603 and median of 531 seconds.

Table 12 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types for Smoldering Source Events Detected by the two Volume Sensor Prototypes, FM1 and FM2

Test ID	Source Description	FM1			FM2		
		Alarm	**Response**	**Type**	**Alarm**	**Response**	**Type**
VS4-007*	Cable Bundle	10:40:15	673	S	10:41:17	735	S
VS4-023	Cable Bundle	14:13:35	453	S	14:34:17	1695	S
VS4-039	Cable Bundle	17:02:08	1921	S	17:04:07	2040	S
VS4-061	Cable Bundle	14:35:44	1782	S	14:46:14	2412	S
VS4-069	Cable Bundle	10:50:16	435	S	11:00:08	1027	S
VS4-084*	Cable Bundle	10:41:01	414	S	10:44:32	625	S
VS4-011	Laundry	14:18:03	239	S	14:18:27	263	S
VS4-030*	Laundry	10:25:09	184	S	10:26:30	265	S
VS4-041	Laundry	8:54:32	207	S	8:55:44	279	S
VS4-094	Laundry	9:00:16	189	S	9:00:55	228	S
VS4-095	Laundry - Camera 4 tilted up	9:43:12	191	S	9:44:08	247	S
VS4-097	Laundry - Camera 4 tilted up	12:23:20	440	S	12:23:54	474	S
VS4-003*	Mattress and Bedding	15:55:35	485	S	15:58:06	636	S
VS4-021*	Mattress and Bedding	12:07:05	365	S	12:07:17	377	S
VS4-036*	Mattress and Bedding	14:30:33	332	S	14:42:20	1039	F
VS4-017	Oily Rags	9:24:25	445	S	9:27:07	607	S
VS4-033	Oily Rags	12:42:00	250	S	12:43:06	316	S
VS4-046	Oily Rags	11:43:01	539	S	11:45:02	660	S
VS4-086*	Oily Rags	12:45:22	322	S	12:48:54	534	S
VS4-048	Painted bulkhead heating	14:01:51	268	S	14:00:54	211	S
VS4-063	Painted bulkhead heating	16:11:21	496	S	16:11:52	527	S
VS4-078	Painted bulkhead heating	16:07:27	371	S	16:08:01	405	S

*Transitioned to flaming

The response of the Fusion Machines to a wide array of nuisance source events is documented in Table 13. Both FM1 and FM2 performed well with FM1 recording 9 false alarms and FM2 recording 7 false alarms out of 32 events. The 9 false alarms for FM1 include 7 false alarms from the data fusion smoke algorithm and 2 from the data fusion flame algorithm. The 7 false alarms for FM2 are composed of 4 false alarms from the data fusion smoke algorithm, 2 false alarms from the data fusion flame algorithm, and 1 false alarm from the data fusion pipe rupture algorithm, test VS4-016, during an Engine Exhaust nuisance test. Note that the Fusion Machines generated false alarms for both Engine Exhaust tests, VS4-016 and VS4-064. FM1 produced false smoke alarms for both tests, and FM2 recorded a false smoke alarm for VS4-064, and the false pipe rupture alarm mentioned earlier for VS4-016. Note also that the data fusion pipe rupture algorithm false alarmed on both Fusion Machines during these same tests, but subsequent to the false smoke alarms listed in Table 13. The rest of the false alarms break down as follows. The commercial VID smoke detection algorithms triggered all false fusion smoke algorithm alarms except those of test VS4-020 for FM2, and test VS4-055 for both Fusion Machines, which were triggered by the SBVS smoke detection algorithm. Lastly, the combination of SBVS and LWVD flame detections triggered all of two false data fusion flame algorithm alarms.

Table 13 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types for Nuisance Source Events Detected by the two Volume Sensor Prototypes, FM1 and FM2

Test ID	Source Description	FM1			FM2		
		Alarm	**Response**	**Type**	**Alarm**	**Response**	**Type**
VS4-066	Aerosol	9:28:44	29	S	DNA	DNA	DNA
VS4-013	AM/FM Radio/Cassette player	DNA	DNA	DNA	DNA	DNA	DNA
VS4-016	Engine Exhaust	8:39:28	208	S	8:43:42	462	P
VS4-064	Engine Exhaust	8:40:24	242	S	8:41:05	283	S
VS4-067	Flash Photography	DNA	DNA	DNA	DNA	DNA	DNA
VS4-081	Flash Photography with four people	DNA	DNA	DNA	DNA	DNA	DNA
VS4-014	Grinding Painted Steel	15:48:03	358	F	15:48:04	359	F
VS4-035	Grinding Painted Steel	DNA	DNA	DNA	DNA	DNA	DNA
VS4-056	Grinding Painted Steel	11:25:36	455	S	DNA	DNA	DNA
VS4-077	Grinding Painted Steel	15:15:55	111	F	15:15:53	109	F
VS4-085	Grinding Painted Steel	DNA	DNA	DNA	DNA	DNA	DNA
VS4-034	Heat gun/space heater/fan	DNA	DNA	DNA	DNA	DNA	DNA
VS4-024	Normal Toasting	DNA	DNA	DNA	DNA	DNA	DNA
VS4-029	People working in space - clean up pipe rupture	DNA	DNA	DNA	DNA	DNA	DNA
VS4-052	People working in space - clean up pipe rupture	DNA	DNA	DNA	9:51:11	61	S
VS4-055	People working in space - clean up pipe rupture	11:05:39	513	S	11:05:39	513	S
VS4-098	Space heater	DNA	DNA	DNA	DNA	DNA	DNA
VS4-100	Space heater	DNA	DNA	DNA	DNA	DNA	DNA
VS4-012	Spilling Metal Bolts	DNA	DNA	DNA	DNA	DNA	DNA
VS4-092	Tig welding stainless steel	DNA	DNA	DNA	DNA	DNA	DNA
VS4-099	Toaster	DNA	DNA	DNA	DNA	DNA	DNA
VS4-005	Torch Cut Steel	DNA	DNA	DNA	DNA	DNA	DNA
VS4-025	Torch Cut Steel	DNA	DNA	DNA	DNA	DNA	DNA
VS4-089	Torch Cut Steel	DNA	DNA	DNA	DNA	DNA	DNA
VS4-019	TV/People working in space	DNA	DNA	DNA	DNA	DNA	DNA
VS4-020	TV with video	11:47:41	396	S	11:47:53	408	S

Table 13 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types for Nuisance Source Events Detected by the two Volume Sensor Prototypes, FM1 and FM2 (Continued)

Test ID	Source Description	FM1			FM2		
		Alarm	Response	Type	Alarm	Response	Type
VS4-004	VHF Radio/People working	DNA	DNA	DNA	DNA	DNA	DNA
VS4-010	Waving materials	13:58:25	385	S	DNA	DNA	DNA
VS4-002	Welding	DNA	DNA	DNA	DNA	DNA	DNA
VS4-083	Welding	DNA	DNA	DNA	DNA	DNA	DNA
VS4-008	Welding (140 A)	DNA	DNA	DNA	DNA	DNA	DNA
VS4-090	Welding preceded by no, normal and high ventilation	DNA	DNA	DNA	DNA	DNA	DNA

DNA = Did Not Alarm

Table 14 presents the response of the Fusion Machines to pipe rupture events. Both Fusion Machines correctly identified 15 out of 16 pipe rupture tests, missing only test VS4-093. Table 14 lists first alarm detections for FM1 from the data fusion smoke algorithm for tests VS4-057 and VS4-093, both triggered by the SFA VID system's smoke detection algorithm. The pipe rupture detection capabilities of the VID systems are discussed in Section 6.2. For VS4-057, the FM1 data fusion pipe rupture algorithm generated an alarm subsequent to the listed smoke alarm. For FM1, the average response time was 84 seconds with a standard deviation of 49.0 and median of 63 seconds. For FM2, the average response time was 84 seconds with a standard deviation of 49.1 and median of 62 seconds, essentially identical to those of FM1.

Table 14 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types for Pipe Rupture Source Events Detected by the two Volume Sensor Prototypes, FM1 and FM2

Test ID	Source Description	FM1			FM2		
		Alarm	Response	Type	Alarm	Response	Type
VS4-028	Pipe rupture - 1 m above deck, 40 psi	9:53:05	65	P	9:53:05	65	P
VS4-054	Pipe rupture - 1 m above deck, 40 psi	10:45:01	60	P	10:45:00	59	P
VS4-093	Pipe rupture - Bete P80 nozzle orifice, 44-149 psi	8:27:52	172	S	DNA	DNA	DNA
VS4-031	Pipe rupture - gash 10" x 0.125", 40 psi	11:11:55	53	P	11:11:56	54	P
VS4-045	Pipe rupture - gash 10" x 0.125", 40 psi	11:17:16	135	P	11:17:16	135	P
VS4-049	Pipe rupture - gash 10" x 0.125", 40 psi	8:19:00	60	P	8:18:59	59	P
VS4-051	Pipe rupture - gash 10" x 0.125", 40 psi	9:42:05	64	P	9:42:05	64	P
VS4-062	Pipe rupture - gash 10" x 0.125", 40 psi	15:36:01	61	P	15:36:00	60	P

Table 14 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types for Pipe Rupture Source Events Detected by the two Volume Sensor Prototypes, FM1 and FM2 (Continued)

Test ID	Source Description	FM1			FM2		
		Alarm	Response	Type	Alarm	Response	Type
VS4-087	Pipe rupture - gash 10" x 0.125", 40 psi	13:30:10	69	P	13:30:10	69	P
VS4-065	Pipe rupture - gash 10" x 0.125", 40 psi against boxes	9:05:02	62	P	9:05:00	60	P
VS4-071	Pipe rupture - gash 10" x 0.125", 40 psi against mattress	12:54:03	63	P	12:54:02	62	P
VS4-072	Pipe rupture - gash 10" x 0.125", 40 psi against mattress	13:09:09	69	P	13:09:09	69	P
VS4-037	Pipe rupture - sprinkler nozzle, 1 m above deck	15:04:54	54	P	15:04:55	55	P
VS4-057	Pipe rupture - sprinkler nozzle, 1 m above deck	12:24:31	31	S	12:27:12	192	P
VS4-079	Pipe rupture - sprinkler nozzle, 1 m above deck	8:05:56	55	P	8:05:56	55	P
VS4-060	Pipe rupture - water mist nozzle, 1 m above deck	13:47:17	197	P	13:47:17	197	P

DNA = Did Not Alarm

5.3 SBVS, Acoustics, and LWVD Sensor Systems

Alarm times, response times, and alarm types obtained for VS component sensor systems developed at NRL are presented in this section. Sensor data from the SBVS, LWVD, and ACST sensor systems were duplicated and sent to both Fusion Machines; therefore, the alarm and response times listed in Tables 15, 16, 17 and 18 can be assumed to be identical for the two Volume Sensor prototypes. Table 15 lists the results for flaming fire events, Table 16 lists the results for smoldering fire events, Table 17 lists the results for nuisance source events, and Table 18 lists the results for pipe rupture events. In these tables, the words flaming, smoldering, nuisance, and pipe rupture have been excised from the test descriptions for brevity.

The format for Tables 15 to 18 is very similar to that used for the Fusion Machines. For all tables, the alarm times are provided in hh:mm:ss format, the response times in seconds after the source initiation time, and the alarm types indicate which sensor system algorithm generated the alarm: flame (F), smoke (S), welding (W), nuisance (N), or pipe rupture (P). Negative response times indicate an alarm prior to source initiation and are counted as false alarms for that sensor system. Additionally, the first two columns give the test number and test description.

For Tables 15 and 16, columns 3 and 4 list the alarm and response times for the LWVD sensor system, columns 5, 6, and 7 list the alarm times, response times, and alarm type for the SBVS sensor system, and columns 8 and 9 list the alarm and response times for the ACST sensor system. For all entries in Tables 15 and 16, the LWVD alarm type is (F), the ACST alarm type is (N). For Table 17, the ACST alarm type is provided in column 10 as nuisance (N), or pipe rupture (P). The LWVD alarm type is (F). In Table 18, column 3 lists alarm times for the LWVD sensor system, column 4 lists alarm times for the SBVS sensor system, and columns 5, 6, and 7 list the alarm times, response times, and alarm type for the ACST sensor system. For all tables, a listed alarm time is always the first alarm time observed for that sensor system algorithm based on all three VS sensor suites of instruments. A "DNA" in a cell means the component or system did not alarm (DNA).

Table 15 documents the response of the LWVD, SBVS, and ACST sensor systems to flaming fire sources. The LWVD and SBVS correctly detected every flaming fire source via their respective flame detection algorithms, except the SBVS for tests VS4-022, VS4-082, and VS4-096, which detected these flaming fires with the smoke detection algorithm. Note in particular, the extremely rapid response times for the detection of IPA spill fires. The ACST pipe rupture did not alarm for any flaming fire sources, however, the ACST nuisance algorithm false alarmed during test VS4-082. For LWVD, the average response time was 181 seconds with a standard deviation of 212 and median of 130 seconds. For SBVS, the average response time was 192 seconds with a standard deviation of 245 and median of 124 seconds.

Table 15 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types[1] for Flaming Source Events Detected by the LWVD, SBVS, and ACST Systems

Test ID	Source Description	LWVD		SBVS			ACST	
		Alarm	Response	Alarm	Response	Type	Alarm	Response
VS4-001	Cardboard Boxes with Polystyrene pellets	13:38:50	152	13:38:52	154	F	DNA	DNA
VS4-018	Cardboard Boxes with Polystyrene pellets	10:28:53	53	10:30:39	159	F	DNA	DNA
VS4-026	Cardboard Boxes with Polystyrene pellets	16:36:25	142	16:36:52	169	F	DNA	DNA
VS4-058	Cardboard Boxes with Polystyrene pellets	12:49:40	100	12:50:23	143	F	DNA	DNA
VS4-070	Cardboard Boxes with Polystyrene pellets	12:14:02	117	12:15:02	177	F	DNA	DNA
VS4-082	Cardboard Boxes with Polystyrene pellets	9:33:21	259	9:31:27	145	S	9:37:07	485
VS4-091	Hot metal surface - IPA spill under slanted cab door	16:06:09	3	16:06:10	4	F	DNA	DNA
VS4-015	IPA Spill Fire/Trash bag	16:08:10	6	16:08:14	10	F	DNA	DNA
VS4-032	IPA Spill Fire/Trash Bag	11:29:17	7	11:29:18	8	F	DNA	DNA
VS4-044	IPA Spill Fire/Trash Bag	10:47:37	7	10:47:38	8	F	DNA	DNA
VS4-053	IPA Spill Fire/Trash Bag	10:19:15	6	10:19:23	14	F	DNA	DNA
VS4-068	IPA Spill Fire/Trash Bag	10:05:14	7	10:05:20	13	F	DNA	DNA
VS4-009	Shipping Supplies	13:07:16	100	13:07:38	122	F	DNA	DNA
VS4-027	Shipping Supplies	8:50:20	142	8:55:12	434	F	DNA	DNA
VS4-043	Shipping Supplies	9:46:36	486	9:57:14	1124	F	DNA	DNA

Table 15 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types[1] for Flaming Source Events Detected by the LWVD, SBVS, and ACST Systems (Continued)

Test ID	Source Description	LWVD		SBVS			ACST	
		Alarm	Response	Alarm	Response	Type	Alarm	Response
VS4-050	Shipping Supplies	8:50:11	68	8:52:02	179	F	DNA	DNA
VS4-006	Trash Can	9:40:07	64	9:40:21	78	F	DNA	DNA
VS4-022	Trash Can	13:20:09	65	13:29:30	626	S	DNA	DNA
VS4-038	Trash Can	15:54:17	15	15:55:50	108	F	DNA	DNA
VS4-096	Trash Can - Camera 4 tilted up	10:47:53	51	10:52:40	338	S	DNA	DNA

DNA = Did Not Alarm
[1]The alarm type of all alarms is (F) for LWVD entries and (N) for ACST entries.

Table 16 lists the response of the LWVD, SBVS and ACST sensor systems to smoldering fires. Note that test ID's marked with a "*" denote tests where the smoldering material transitioned to flaming material. The SBVS system detected 10 of the 22 smoldering fires, with the SBVS smoke algorithm detecting six of the sources, and the SBVS flame algorithm detected an additional four sources after they had transitioned to flaming fires. The LWVD system detected 14 of the 22 smoldering fires, which includes all seven sources after they had transitioned to flaming sources. The LWVD system was able to detect the other smoldering fires from smoke blooming on the lights or hot objects. The LWVD system false alarmed during test VS4-086, possibly due to human activity in the compartment, but subsequently correctly alarmed on the transitioned source. The ACST pipe rupture algorithm did not alarm for any smoldering sources. The ACST HF Nuisance algorithm generated a gas release alert during test VS4-061 due to the leaking of air from a SCBA when safety personnel entered the compartment. For LWVD, the average response time was 1019 seconds with a standard deviation of 584 and median of 946 seconds. For SBVS, the average response time for all entries was faster at 995 seconds with a standard deviation of 529 and median of 917 seconds.

Table 16 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types[1] for Smoldering Source Events Detected by the LWVD, SBVS, and ACST Systems

Test ID	Source Description	LWVD		SBVS			ACST	
		Alarm	Response	Alarm	Response	Type	Alarm	Response
VS4-007*	Cable Bundle	11:04:46	2144	11:04:44	2142	F	DNA	DNA
VS4-023	Cable Bundle	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-039	Cable Bundle	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-061	Cable Bundle	DNA	DNA	DNA	DNA	DNA	14:33:02	1620
VS4-069	Cable Bundle	11:08:08	1507	DNA	DNA	DNA	DNA	DNA
VS4-084*	Cable Bundle	11:00:57	1610	DNA	DNA	DNA	DNA	DNA
VS4-011	Laundry	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-030*	Laundry	10:35:19	794	DNA	DNA	DNA	DNA	DNA
VS4-041	Laundry	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-094	Laundry	9:07:40	633	DNA	DNA	DNA	DNA	DNA

Table 16 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types[1] for Smoldering Source Events Detected by the LWVD, SBVS, and ACST Systems (Continued)

Test ID	Source Description	LWVD		SBVS			ACST	
		Alarm	Response	Alarm	Response	Type	Alarm	Response
VS4-095	Laundry - Camera 4 tilted up	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-097	Laundry - Camera 4 tilted up	12:30:32	872	DNA	DNA	DNA	DNA	DNA
VS4-003*	Mattress and Bedding	16:11:47	1457	16:11:54	1464	F	DNA	DNA
VS4-021*	Mattress and Bedding	12:20:44	1184	12:19:53	1133	S	DNA	DNA
VS4-036*	Mattress and Bedding	14:42:01	1020	14:42:07	1026	F	DNA	DNA
VS4-017	Oily Rags	9:40:16	1396	9:37:41	1241	S	DNA	DNA
VS4-033	Oily Rags	12:47:52	602	12:45:52	482	S	DNA	DNA
VS4-046	Oily Rags	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-086*	Oily Rags	12:36:32	-208	12:53:27	807	F	DNA	DNA
VS4-048	Painted bulkhead heating	14:06:25	542	14:05:43	500	S	DNA	DNA
VS4-063	Painted bulkhead heating	DNA	DNA	16:14:04	659	S	DNA	DNA
VS4-078	Painted bulkhead heating	16:13:06	710	16:09:34	498	S	DNA	DNA

DNA = Did Not Alarm
*Transitioned to flaming
[1]The alarm type of all alarms is (F) for LWVD entries and (N) for ACST entries.

The response of the LWVD, SBVS and ACST sensor systems to the 32 nuisance source events is shown in Table 17. The LWVD system generated false alarms for eleven of the nuisance sources. The SBVS system generated false alarms, types (F) and (S), for four of the nuisance sources, but correctly classified all of the torch cutting and welding nuisance events as type (W). Note that the SBVS system correctly classified test VS4-089 as type (W) subsequent to the listed false alarm of type (F). The nuisance algorithm of the ACST sensor system correctly classified 19 of the 32 nuisance sources, including test VS4-090 subsequent to the false alarm. This ACST nuisance algorithm false alarm for VS4-090 appears to have been caused by changes in the ventilation settings prior to source initiation triggering the Grinding algorithm. The second set of times is the HF Nuisance algorithm correctly generating an alert on the event. The ACST pipe rupture algorithm generated false alarms during both of the Engine Exhaust tests, VS4-016 and VS4-064, at times subsequent to the listed ACST nuisance alerts for these tests. Finally, note the rapid response of the LWVD system to the bright nuisance sources: welding, grinding, and torch cutting, and the similarly rapid response nuisance alerts of the SBVS system. Response times for the ACST nuisance alerts are also quite fast.

Table 17 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types[1] for Nuisance Source Events Detected by the LWVD, SBVS, and ACST Systems

Test ID	Source Description	LWVD		SBVS			ACST		
		Alarm	Response	Alarm	Response	Type	Alarm	Response	Type
VS4-066	Aerosol	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-013	AM/FM Radio/Cassette player	DNA	DNA	DNA	DNA	DNA	15:23:21	21	N
VS4-016	Engine Exhaust	DNA	DNA	DNA	DNA	DNA	8:40:18	258	N
VS4-064	Engine Exhaust	DNA	DNA	DNA	DNA	DNA	8:36:56	34	N
VS4-067	Flash Photography	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-081	Flash Photography with four people	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-014	Grinding Painted Steel	15:42:17	12	15:45:38	213	F	15:42:31	26	N
VS4-035	Grinding Painted Steel	DNA	DNA	DNA	DNA	DNA	13:57:24	19	N
VS4-056	Grinding Painted Steel	DNA	DNA	DNA	DNA	DNA	11:18:23	22	N
VS4-077	Grinding Painted Steel	15:14:09	5	15:15:32	88	F	15:14:20	16	N
VS4-085	Grinding Painted Steel	12:21:40	40	DNA	DNA	DNA	12:21:13	13	N
VS4-034	Heat gun/space heater/fan	DNA	DNA	DNA	DNA	DNA	13:31:46	43	N
VS4-024	Normal Toasting	DNA	DNA	DNA	DNA	DNA	15:21:14	13	N
VS4-029	People working in space - clean up pipe rupture	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-052	People working in space - clean up pipe rupture	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-055	People working in space - clean up pipe rupture	DNA	DNA	11:05:28	502	S	10:59:53	167	N
VS4-098	Space heater	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-100	Space heater	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-012	Spilling Metal Bolts	DNA	DNA	DNA	DNA	DNA	15:06:33	26	N
VS4-092	Tig welding stainless steel	16:38:04	4	16:38:15	15	W	DNA	DNA	DNA
VS4-099	Toaster	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-005	Torch Cut Steel	8:44:24	22	8:45:04	62	W	8:44:53	51	N
VS4-025	Torch Cut Steel	15:57:35	3	15:58:13	41	W	15:58:26	54	N
VS4-089	Torch Cut Steel	15:03:05	3	15:03:07	5	F	15:03:55	53	N
VS4-019	TV/People working in space	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-020	TV with video	DNA	DNA	11:47:43	398	S	DNA	DNA	DNA
VS4-004	VHF Radio/People working	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-010	Waving materials	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-002	Welding	14:38:06	4	14:38:06	4	W	14:38:53	51	N
VS4-083	Welding	10:10:07	4	10:10:08	5	W	10:10:38	35	N
VS4-008	Welding (140 A)	12:23:08	6	12:23:09	7	W	12:23:42	40	N
VS4-090	Welding preceded by no, normal and high ventilation	15:36:06	3	15:36:08	5	W	15:28:06 15:36:33	-477 30	N N

DNA = Did Not Alarm

[1]The alarm types (W) and (N) indicate nuisance *alerts*.

Table 18 documents the response of the LWVD, SBVS, and ACST sensor systems for pipe rupture sources. The LWVD and SBVS systems did not generate any alarms during pipe rupture tests. The pipe rupture algorithm of the ACST system correctly detected 15 of the 16 pipe rupture sources. The one source it missed, test VS4-093, employed a small, and consequently quieter nozzle flow. People working in the space to change out the original clogged nozzle during the background collecting portion of the test appear to have been the source of background noise at high enough levels to raise the ACST background estimation to a level that prevented the pipe rupture algorithm from generating an alarm, though it did reach a pre-alarm level. Note that the alarm time listed for test VS4-045 is subsequent to source termination. The ACST pipe rupture algorithm bases its alarm decision on the most recent 30 seconds of audio information. During this test, the algorithm was very close to an alarm level, finally reaching it just after source termination while water was still draining from the pipe onto the floor of the compartment. Note also that the ACST nuisance algorithm generated an unlisted false alert as the water pressure was increased during test VS4-060. The ACST pipe rupture detection average response time was 64 seconds with a standard deviation of 40 and median of 50 seconds.

Table 18 — Alarm Times, Response Times (in Seconds from Source Initiation), and Alarming Algorithm Types for Pipe Rupture Source Events Detected by the LWVD, SBVS, and ACST Systems

Test ID	Source Description	LWVD	SBVS	ACST		
		Alarm	Alarm	Alarm	Response	Type
VS4-028	Pipe rupture - 1 m above dk, 40 psi	DNA	DNA	9:52:55	55	P
VS4-054	Pipe rupture - 1 m above dk, 40 psi	DNA	DNA	10:44:50	49	P
VS4-093	Pipe rupture - Bete P80 nozzle orifice, 44-149 psi	DNA	DNA	DNA	DNA	DNA
VS4-031	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	11:11:45	43	P
VS4-045	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	11:17:06	125	P
VS4-049	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	8:18:49	49	P
VS4-051	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	9:41:55	54	P
VS4-062	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	15:35:50	50	P
VS4-087	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	13:29:59	58	P
VS4-065	Pipe rupture - gash 10" x 0.125", 40 psi against boxes	DNA	DNA	9:04:50	50	P
VS4-071	Pipe rupture - gash 10" x 0.125", 40 psi against mattress	DNA	DNA	12:53:51	51	P
VS4-072	Pipe rupture - gash 10" x 0.125", 40 psi against mattress	DNA	DNA	13:08:58	58	P
VS4-037	Pipe rupture - sprinkler nozzle, 1 m above dk	DNA	DNA	15:04:44	44	P
VS4-057	Pipe rupture - sprinkler nozzle, 1 m above dk	DNA	DNA	12:24:42	42	P
VS4-079	Pipe rupture - sprinkler nozzle, 1 m above dk	DNA	DNA	8:05:46	45	P
VS4-060	Pipe rupture - water mist nozzle, 1 m above dk	DNA	DNA	13:47:07	187	P

DNA = Did Not Alarm

5.4 VID System Performance

Tables 19 though 22 provide the alarm times for the VID systems, spot-type smoke detectors, and the VS Fusion Machines for the VS4 Test Series. The last row in each table provides the number of alarms per the number of events for each detection system. The ionization and photoelectric spot-type smoke detection systems are treated as independent, full-space systems. For example, the EST Ion alarm time represents the fastest alarm time achieved by any of the four ion detectors within the test space. In a similar fashion, the VS Fusion Machine and VID system times represent the fastest time obtained from any of the three VS suites/cameras. Table 19 presents the alarm times for the flaming fire source tests, and Table 20 presents the smoldering fire results. The alarm time responses for the nuisance source tests are included in Table 21. Table 22 lists the results produced by the VID systems during the pipe rupture tests. These alarm responses are utilized in comparative analyses of the different detection systems and are discussed in Sections 6.1 and 6.2. Note that the alarm times reported in this section for the VID systems were those recorded by the VID systems, as differentiated from VID alarm times transmitted to the Fusion Machines.

As discussed previously, the VS fusion systems evaluated in this test series utilized the smoke alarm outputs from the commercial VID systems. For the detection of smoke, the data fusion smoke detection algorithm relied heavily on the VID system smoke algorithm (see Section 4.6.2). The alarm times received from the Signifire and SFA systems matched the recorded times of the Fusion Machines with only small deviations of several seconds. The alarm times presented in Tables 19 to 22 include the instantaneous SFA and SigniFire alarm times. Appendix B in the attached CD contains the alarm times directly recorded by the FM systems. A detailed discussion of these tables is presented in the following section.

The alarm responses presented in Tables 19 to 22 were used to compare the overall event detection capabilities of the Volume Sensor Prototype and commercial fire detection systems. Times in **black bold** are the quickest response time per test between the COTS systems. Times in a shaded table cell are Fusion Machine alarms that alarmed faster than all three COTS systems.

6.0 DISCUSSION

6.1 Functionality of Multi-component VS Prototype

As noted previously, the XML-based communications protocol for transmitting command and data packets between Volume Sensor components over the ship's TCP/IP network worked very well, even when portions of the ship's network were heavily loaded. Alarm times and scaled data from the sensor systems were reliably and accurately transmitted to the Fusion Machines.

Table 19 — Alarm Times (Min:Sec) for the Spot-Type Smoke Detection Systems, Commercial VID Systems, and the VS Fusion Machines for Flaming Fire Sources

Test	Brief Source Description	EST		FM1	SFA			FM2	SigniFire			
		Ion	Photo		Smoke	Fire	Smoke and Fire		Offsite	Smoke	Fire	Offsite, Smoke and Fire
VS4-001	Flaming Cardboard Boxes with Polystyrene pellets	**01:40**	02:48	02:45(S)	02:33	DNA	02:33	02:54(S)	03:05	02:43	DNA	02:43
VS4-018	Flaming Cardboard Boxes with Polystyrene pellets	01:56	01:44	01:43(S)	01:36	03:10	01:36	01:45(S)	**01:00**	01:34	DNA	**01:00**
VS4-026	Flaming Cardboard Boxes with Polystyrene pellets	**00:47**	04:06	03:00(F)	03:11	DNA	03:11	02:60(F)	03:53	04:52	DNA	03:53
VS4-058	Flaming Cardboard Boxes with Polystyrene pellets	00:56	01:31	02:20(S)	02:08	04:32	02:08	02:34(F)	01:41	02:56	**00:50**	**00:50**
VS4-070	Flaming Cardboard Boxes with Polystyrene pellets	**01:20**	02:31	03:34(S)	03:20	02:35	02:35	03:10(S)	04:44	03:04	02:09	02:09
VS4-082	Flaming Cardboard Boxes with Polystyrene pellets	**00:48**	01:32	02:11(S)	01:58	06:44	01:58	02:14(S)	04:29	02:05	04:29	02:05
VS4-015	Flaming IPA Spill Fire/Trash bag	00:57	DNA	00:20(F)	DNA	DNA	DNA	00:20(F)	**00:17**	DNA	DNA	**00:17**
VS4-032	Flaming IPA Spill Fire/Trash bag	00:55	04:00	**00:18(F)**	01:27	01:55	01:27	**00:19(F)**	**00:24**	**00:24**	**00:24**	**00:24**
VS4-044	Flaming IPA Spill Fire/Trash bag	**00:33**	04:08	**00:18(F)**	02:01	DNA	02:01	**00:18(F)**	00:54	04:09	DNA	00:54
VS4-053	Flaming IPA Spill Fire/Trash bag	00:43	04:17	00:25(F)	03:02	00:31	00:31	00:24(F)	00:08	03:28	**00:07**	**00:07**
VS4-068	Flaming IPA Spill Fire/Trash Bag	00:58	DNA	**00:25(F)**	02:14	DNA	02:14	**00:23(F)**	**00:25**	04:36	DNA	**00:25**
VS4-009	Flaming Shipping Supplies	**01:53**	DNA	02:01(S)	**01:53**	DNA	**01:53**	02:12(S)	11:50	02:05	DNA	02:05

Table 19 — Alarm Times (Min:Sec) for the Spot-Type Smoke Detection Systems, Commercial VID Systems, and the VS Fusion Machines for Flaming Fire Sources (Continued)

Test	Brief Source Description	EST		FM1	SFA			FM2	SigniFire			
		Ion	Photo		Smoke	Fire	Smoke and Fire		Offsite	Smoke	Fire	Offsite, Smoke and Fire
VS4-027	Flaming Shipping Supplies	04:12	DNA	00:41(S)	**00:33**[1]	DNA	**00:33**[1]	11:21(F)	06:30	22:48	DNA	06:30
VS4-043	Flaming Shipping Supplies	**01:31**	16:54	17:13(S)	17:04	DNA	17:04	16:33(S)	DNA	16:23	DNA	16:23
VS4-050	Flaming Shipping Supplies	**01:38**	DNA	02:18(S)	14:14	05:30	05:30	03:09(F)	07:08	10:28	03:2 9	03:29
VS4-006	Flaming Trash Can	**01:25**	02:38	01:30(F)	02:00	DNA	02:00	01:30(F)	DNA	03:09	DNA	03:09
VS4-022	Flaming Trash Can	DNA	DNA	05:05(S)	**04:59**	DNA	**04:59**	10:37(S)	DNA	10:39	DNA	10:39
VS4-038	Flaming Trash Can	**00:29**	03:05	02:18(F)	02:51	DNA	02:51	02:03(F)	DNA	03:13	DNA	03:13
VS4-096	Flaming Trash Can	01:15	04:39	03:59(S)	03:45	02:12	02:12	04:05(S)	DNA	03:55	**00:5 0**	**00:50**
VS4-091	Hot metal surface – shielded IPA spill fire	DNA	DNA	**00:17(F)**	**03:33**[1]	DNA	**03:33**[1]	**00:17(F)**	DNA	DNA	DNA	DNA
Ratio of Alarms/Tests (# of tests that system or algorithm was first to alarm)		18/20 (10)	13/20 (0)	20/20 (4)	19/20 (4)	8/20 (0)	19/20 (4)	20/20 (4)	14/20 (4)	18/20 (1)	7/20 (4)	19/20 (7)

DNA = Did Not Alarm

[1]denotes an alarm that activated due to the aft compartment door

Table 20 — Alarm Times (Min:Sec) for the Spot-Type Smoke Detection Systems, Commercial VID Systems, and the VS Fusion Machines for Smoldering Fire Sources

Test	Brief Source Description	EST		FM1	SFA			FM2	SigniFire			
		Ion	Photo		Smoke	Fire	Smoke and Fire		Offsite	Smoke	Fire	Offsite, Smoke and Fire
VS4-048	Painted bulkhead heating	06:28	04:56	04:28(S)	04:18	DNA	04:18	03:31(S)	DNA	**03:22**	DNA	**03:22**
VS4-063	Painted bulkhead heating	**06:02**	08:35	08:16(S)	08:05	DNA	08:05	08:47(S)	DNA	08:40	DNA	08:40
VS4-078	Painted bulkhead heating	**04:58**	07:03	06:11(S)	05:58	DNA	05:58	06:45(S)	DNA	06:40	DNA	06:40
VS4-007	Smoldering Cable Bundle	29:24	14:10	11:13(S)	**11:05**	DNA	**11:05**	12:15(S)	DNA	12:07	DNA	12:07
VS4-023	Smoldering Cable Bundle	30:18	**05:58**	07:33(S)	07:26	DNA	07:26	28:15(S)	DNA	28:05	DNA	28:05
VS4-039	Smoldering Cable Bundle	26:30	**18:57**	32:01(S)	31:54	DNA	31:54	34:00(S)	DNA	33:52	DNA	33:52
VS4-061	Smoldering Cable Bundle	DNA	34:30	29:42(S)	**29:31**	DNA	**29:31**	40:12(S)	DNA	40:04	DNA	40:04
VS4-069	Smoldering Cable Bundle	DNA	11:04	07:15(S)	**07:01**	DNA	**07:01**	17:07(S)	DNA	17:01	DNA	17:01
VS4-084*	Smoldering Cable Bundle	29:50	09:53	06:54(S)	**06:42**	DNA	**06:42**	10:25(S)	DNA	10:15	DNA	10:15
VS4-011	Smoldering Laundry	07:27	05:57	03:59(S)	**03:51**	DNA	**03:51**	04:23(S)	DNA	04:15	DNA	04:15
VS4-030*	Smoldering Laundry	15:28	05:08	03:04(S)	**02:55**	DNA	**02:55**	04:25(S)	DNA	04:14	DNA	04:14
VS4-041	Smoldering Laundry	04:21	05:10	03:27(S)	**03:15**	DNA	**03:15**	04:39(S)	DNA	04:28	DNA	04:28
VS4-094	Smoldering Laundry	DNA	DNA	03:09(S)	**02:56**	DNA	**02:56**	03:48(S)	DNA	03:39	DNA	03:39
VS4-095	Smoldering Laundry	06:57	04:09	03:11(S)	**02:56**	DNA	**02:56**	04:07(S)	DNA	03:57	DNA	03:57

Table 20 — Alarm Times (Min:Sec) for the Spot-Type Smoke Detection Systems, Commercial VID Systems, and the VS Fusion Machines for Smoldering Fire Sources (Continued)

Test	Brief Source Description	EST		FM1	SFA			FM2	SigniFire			
		Ion	Photo		Smoke	Fire	Smoke and Fire		Offsite	Smoke	Fire	Offsite, Smoke and Fire
VS4-097	Smoldering Laundry	11:46	08:33	07:20(S)	**07:06**	DNA	**07:06**	07:54(S)	DNA	07:44	DNA	07:44
VS4-003	Smoldering Mattress and Bedding	24:55	10:23	08:05(S)	**07:58**	DNA	**07:58**	10:36(S)	DNA	10:25	DNA	10:25
VS4-021*	Smoldering Mattress and Bedding	18:48	07:28	06:05(S)	**05:59**	DNA	**05:59**	06:17(S)	16:13	06:06	DNA	06:06
VS4-036	Smoldering Mattress and Bedding	06:18	05:30	05:32(S)	**05:24**	DNA	**05:24**	17:19(F)	DNA	17:19	DNA	17:19
VS4-017	Smoldering Oily Rags	22:45	12:39	07:25(S)	**06:54**	DNA	**06:54**	10:07(S)	DNA	09:56	DNA	09:56
VS4-033	Smoldering Oily Rags	09:53	05:11	04:10(S)	**04:01**	DNA	**04:01**	05:16(S)	DNA	05:06	DNA	05:06
VS4-046	Smoldering Oily Rags	DNA	13:10	08:59(S)	**08:51**	DNA	**08:51**	11:00(S)	DNA	10:51	DNA	10:51
VS4-086*	Smoldering Oily Rags	13:50	08:00	05:22(S)	**05:10**	13:52	**05:10**	08:54(S)	15:04	08:44	13:13	08:44
Ratio of Alarms/Tests (# of tests that system or algorithm was first to alarm)		18/22 (2)	21/22 (2)	22/22 (NA)	22/22 (17)	1/22 (0)	22/22 (17)	22/22 (NA)	2/22 (0)	22/22 (1)	1/22 (0)	22/22 (1)

DNA = Did Not Alarm.
NA = The Fusion Machines use the smoke output of the VID systems as the primary activation criteria.
* = Fire transitioned from smoldering to flaming

Table 21 — Alarm Times (Min:Sec) for the Spot-Type Smoke Detection Systems, Commercial VID Systems, and the VS Fusion Machines for Nuisance Sources

Test	Brief Source Description	EST		FM1	SFA			FM2	SigniFire			
		Ion	**Photo**		**Smoke**	**Fire**	**Smoke and Fire**		**Offsite**	**Smoke**	**Fire**	**Offsite, Smoke and Fire**
VS4-066	Aerosol	DNA	DNA	00:29(S)	**00:16**	01:29	**00:16**	DNA	DNA	DNA	DNA	DNA
VS4-013	AM/FM Radio/Cassette player	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-016	Engine Exhaust	04:16	DNA	03:28(S)	**03:15**	DNA	**03:15**	07:42(P)	DNA	DNA	DNA	DNA
VS4-064	Engine Exhaust	**01:09**	DNA	04:02(S)	03:47	DNA	03:47	04:43(S)	DNA	04:37	DNA	04:37
VS4-067	Flash Photography	DNA	DNA	DNA	DNA	**03:01**	**03:01**	DNA	DNA	DNA	DNA	DNA
VS4-081	Flash Photography with four people	DNA	DNA	DNA	DNA	**01:33**	**01:33**	DNA	DNA	DNA	DNA	DNA
VS4-014	Grinding Painted Steel	**03:49**	DNA	05:58(F)	DNA	06:08	06:08	05:59(F)	DNA	DNA	DNA	DNA
VS4-305	Grinding Painted Steel	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-056	Grinding Painted Steel	DNA	DNA	07:35(S)	07:23	**04:46**	**04:46**	DNA	DNA	DNA	DNA	DNA
VS4-077	Grinding Painted Steel	**01:10**	DNA	01:51(F)	DNA	02:23	02:23	01:49(F)	DNA	DNA	01:57	01:57
VS4-085	Grinding Painted Steel	**00:57**	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-034	Heat gun/space heater/fan	DNA	DNA	DNA	DNA	**03:46**[1]	**03:46**[1]	DNA	DNA	DNA	DNA	DNA
VS4-024	Normal Toasting	**02:50**	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-029	People working in space - clean up pipe rupture	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-052	People working in space - clean up pipe rupture	DNA	DNA	DNA	DNA	DNA	DNA	01:01(S)	DNA	**00:53**[2]	DNA	**00:53**[2]
VS4-055	People working in space - clean up pipe rupture	DNA	DNA	08:33(S)	DNA	**00:04**[3]	**00:04**[3]	08:33(S)	DNA	DNA	DNA	DNA
VS4-098	Space heater	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-100	Space heater	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	35:02	**31:01**	**31:01**
VS4-012	Spilling Metal Bolts	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-092	Tig welding stainless steel	DNA	DNA	DNA	**00:48**	01:14	**00:48**	DNA	DNA	DNA	DNA	DNA
VS4-099	Toaster	**02:47**	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA

Table 21 — Alarm Times (Min:Sec) for the Spot-Type Smoke Detection Systems, Commercial VID Systems, and the VS Fusion Machines for Nuisance Sources (Continued)

Test	Brief Source Description	EST		FM1	SFA			FM2	SigniFire			
		Ion	Photo		Smoke	Fire	Smoke and Fire		Offsite	Smoke	Fire	Offsite, Smoke and Fire
VS4-005	Torch Cut Steel	**00:34**	DNA	DNA	DNA	03:59	03:59	DNA	DNA	DNA	03:22	03:22
VS4-025	Torch Cut Steel	**00:44**	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-089	Torch Cut Steel	**00:40**	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-019	TV/People working in space	DNA	DNA	DNA	DNA	**14:31**	**14:31**	DNA	DNA	DNA	DNA	DNA
VS4-020	TV with video	DNA	DNA	06:36(S)	06:30[4]	DNA	06:30[4]	06:48(S)	09:20	DNA	**00:16**	**00:16**
VS4-004	VHF Radio/People working	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
VS4-010	Waving materials	DNA	DNA	06:25(S)	**06:18**	DNA	**06:18**	DNA	DNA	DNA	DNA	DNA
VS4-002	Welding	00:44	01:21	DNA	01:05	00:43	00:43	DNA	DNA	DNA	**00:09**	**00:09**
VS4-083	Welding	00:33	**00:29**	DNA	01:14	DNA	01:14	DNA	02:59	02:59	DNA	02:59
VS4-008	Welding (140 A)	02:00	02:10	DNA	01:12	DNA	01:12	DNA	00:41	DNA	**00:16**	**00:16**
VS4-090	Welding proceeded by no, normal and high ventilation	03:51	03:37	DNA	00:53	03:27	00:53	DNA	**00:36**	01:06	00:45	**00:36**
Ratio or Alarms/Tests (# of tests that system or algorithm was first to alarm)		14/32 (9)	4/32 (1)	9/32 (0)	11/32 (4)	13/32 (6)	19/32 (9)	7/32 (0)	4/32 (1)	5/32 (1)	7/32 (4)	10/32 (6)

DNA = Did Not Alarm
[1]denotes an alarm that activated due to person in the compartment
[2]denotes an alarm that activated due to mist in the OH of the compartment
[3]denotes an alarm that activated due to reflections off a pool of water
[4]denotes an alarm that activated due to the opening of the aft compartment door

Table 22 — Alarm Times (Min:Sec) for the Spot-Type Smoke Detection Systems, Commercial VID Systems, and the VS Fusion Machines for Pipe Rupture Events

Test	Brief Source Description	EST		FM1	SFA			FM2	SigniFire			
		Ion	Photo		Smoke	Fire	Smoke and Fire		Offsite	Smoke	Fire	Offsite, Smoke and Fire
VS4-028	Pipe rupture - 1 m above dk, 40 psi	DNA	DNA	**01:05(P)**	DNA	**02:15**	**02:15**	**01:05(P)**	DNA	DNA	DNA	DNA
VS4-054	Pipe rupture - 1 m above dk, 40 psi	DNA	DNA	00:60(P)	03:35	**00:57**	**00:57**	00:59(P)	DNA	DNA	DNA	DNA
VS4-093	Pipe rupture - Bete P80 nozzle orifice, 44-149 psi	DNA	DNA	02:52(S)	**02:41**[1]	DNA	**02:41**[1]	DNA	DNA	DNA	DNA	DNA
VS4-031	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	**00:53(P)**	**02:41**	DNA	**02:41**	**00:54(P)**	DNA	DNA	DNA	DNA
VS4-045	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	**02:15(P)**	DNA	DNA	DNA	**02:15(P)**	DNA	DNA	DNA	DNA
VS4-049	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	**00:60(P)**	DNA	DNA	DNA	**00:59(P)**	DNA	DNA	DNA	DNA
VS4-051	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	**01:04(P)**	**02:28**	DNA	**02:28**	**01:04(P)**	DNA	DNA	DNA	DNA
VS4-062	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	**01:01(P)**	**01:06**	01:34	**01:06**	**00:60(P)**	DNA	DNA	DNA	DNA
VS4-087	Pipe rupture - gash 10" x 0.125", 40 psi	DNA	DNA	**01:09(P)**	DNA	DNA	DNA	**01:09(P)**	DNA	DNA	DNA	DNA
VS4-065	Pipe rupture - gash 10" x 0.125", 40 psi against boxes	DNA	DNA	01:02(P)	DNA	**00:39**	**00:39**	01:00(P)	DNA	DNA	DNA	DNA
VS4-071	Pipe rupture - gash 10" x 0.125", 40 psi against mattress	DNA	DNA	**01:03(P)**	DNA	DNA	DNA	**01:02(P)**	DNA	DNA	DNA	DNA

Table 22 — Alarm Times (Min:Sec) for the Spot-Type Smoke Detection Systems, Commercial VID Systems, and the VS Fusion Machines for Pipe Rupture Events (Continued)

Test	Brief Source Description	EST		FM1	SFA			FM2	SigniFire			
		Ion	Photo		Smoke	Fire	Smoke and Fire		Offsite	Smoke	Fire	Offsite, Smoke and Fire
VS4-072	Pipe rupture - gash 10" x 0.125", 40 psi against mattress	DNA	DNA	01:09(P)	DNA	**01:00**	**01:00**	01:09(P)	DNA	DNA	DNA	DNA
VS4-037	Pipe rupture - sprinkler nozzle, 1 m above dk	DNA	DNA	**00:54(P)**	01:49	DNA	01:49	**00:55(P)**	DNA	**01:45**	DNA	**01:45**
VS4-057	Pipe rupture - sprinkler nozzle, 1 m above dk	DNA	DNA	00:31(S)	**00:19**	DNA	**00:19**	03:12(P)	DNA	DNA	DNA	DNA
VS4-079	Pipe rupture - sprinkler nozzle, 1 m above dk	DNA	DNA	**00:55(P)**	**00:57**	DNA	**00:57**	**00:55(P)**	DNA	02:05	DNA	02:05
VS4-060	Pipe rupture - water mist nozzle, 1 m above dk	DNA	DNA	**03:17(P)**	**04:49**	DNA	**04:49**	**03:17(P)**	DNA	DNA	DNA	DNA
Ratio of Alarms/Tests (# of tests that system was first to alarm)		0/16 (0)	0/16 (0)	16/16 (11)	9/16 (7)	5/16 (4)	12/16 (11)	15/16 (11)	0/16 (0)	2/16 (1)	0/16 (0)	2/16 (1)

DNA = Did Not Alarm
[1]denotes an alarm that activated due to the opening of the aft compartment door

The current test series provided a wealth of high-quality data for future algorithm development and improvements to the sensor systems and Data Fusion Algorithm Module. All component systems recorded data that can be processed and used to reevaluate future revisions of the VS prototype. All video was recorded digitally for efficient future use.

6.2 Source Classification

Table 23 presents a summary of the percent of events correctly classified by the Volume Sensor prototypes, FM1 and FM2, compared to those correctly classified by the VID and spot-type smoke detection systems. The response of each detection system is based on all algorithms used by that system and all sensor inputs to the system. For example, the SFA response for flaming fires is based on both smoke and flame algorithm alarms from any of the three standard cameras. As can be seen in the Table, the results for both VS prototypes are quite similar. The only disparity is directly related to the different results produced by the VID systems' smoke and nuisance alarms. Note that the Volume Sensor prototypes are the only systems that can correctly classify pipe rupture events. In video images, the flow of water from a pipe rupture source often mimics that of smoke from a smoldering source and the VID systems do alarm for pipe rupture sources. However, the VID systems do not yet incorporate pipe rupture detection algorithms, instead, classifying them as a smoke and occasionally, flame events. Therefore in Table 23, the pipe rupture event alarms are not considered correct classifications for the VID systems.

Table 23 — Summary of Events Correctly Classified by FM1, FM2 and the Commercial Fire Detection Systems

Source type (# of tests)	FM 1	SFA	FM 2	SigniFire	EST Ion	EST Photo
Flaming (20)	100%	95%	100%	95%	90%	65%
Smoldering (22)	100%	100%	100%	100%	90%	95%
Nuisance (32)	72%	41%	78%	69%	56%	88%
Pipe Rupture (16)	94%	0%[1]	94%	0%[1]	0%	0%

[1]SFA alarmed for 75% of pipe rupture sources, SigniFire alarmed for 13%.

The VS prototype systems performed well, detecting all of the flaming and smoldering sources and correctly classifying 72 and 78 percent of the nuisance sources, respectively for FM1 and FM2. Compared to both the commercial VID systems and the ion spot-type smoke detection system, the VS prototype systems were both more reliable fire detectors and the most resilient systems to nuisance sources. Only the EST photo system had better nuisance resilience, though at the cost of decreased performance for fire detection. In all of these cases, the VS systems provided both better fire detection capabilities with improved nuisance source immunity. The VS prototypes were effective at properly classifying nuisance sources like the welding and torch cutting of steel events. These events, particularly the welding, caused multiple alarms with the other commercial detection systems. Lastly, the VS prototypes provide reliable and correct pipe rupture detection compared to some incorrectly classified detection capabilities for the VID systems, and none for the ion or photo based systems. In this section some sources are marked with a footnote within the tables to identify alarms that may not be due to the source being tested.

A review of the video history files indicates that certain alarms may have been a result of potential nuisance sources (i.e., a compartment door opening or people in the space). However, the alarms in the tests noted maybe a result of the combination of the changing conditions within the compartment due to the source being tested and the potential nuisance source activity. That is, without the developing fire conditions, the nuisance source would not have triggered an alarm. Due to the subjective nature of these alarms and uncertainty of the exact cause of the alarm in the history files, they have been identified in the tables but are considered alarms in all statistical evaluations.

6.3 Speed of Detection System Response

Based on the alarm times presented in Tables 19 to 22, a comparison of the speed of detection to fires was performed between the VS prototypes and the commercial fire detection systems. For this comparison, it was assumed that time differences of less than 30 seconds denote equivalent response. This 30 second time was arbitrarily selected as a value based on the limited size of the fuel packages and the large response times associated with the smoldering fires.

In general, the VS prototypes were able to provide equivalent or faster responses to flaming fires than the spot-type smoke detection systems. Fusion Machine 1 produced alarms that were the same or faster than the EST ion system in 11 of 20 flaming fires (6 of the 11 were faster). FM1 out performed the EST photo system in 17 of the 20 flaming fire tests (14 of the 17 were faster). The performance of Fusion Machine 2 was very similar. FM2 had response times equivalent or faster in 10 of 20 flaming fires (5 were faster) when compared to the ionization smoke detectors. FM2 out performed the EST photo system in 17 of the 20 flaming fire tests (13 of the 17 were faster). When the VID systems and the Fusion machines are compared it can be seen that FM 1 alarmed faster or obtained similar results in 18 of the 20 flaming fires (7 were faster) when compared to the SFA system and 15 of 20 flaming fires (8 were faster) when compared to the SigniFire system. Similar results were produced by FM2 with 16 out of 20 flaming fire alarms being similar or faster then the SFA system (8 of the alarms were faster), and 15 out of 20 flaming fire alarms being similar or faster than the SigniFire system (5 of the alarms were faster).

For smoldering fires, the SFA VID system alarmed quicker than any other detection system in 17 of the 22 smoldering tests, this was followed by the ion and photo spot type detection systems, which were each the first to alarm in two tests. The SigniFire system was first to alarm in only 1 test. However, if the SFA system is removed from the analysis, the SigniFire VID system alarmed quicker than the smoke detection systems in 11 of the 22 tests, with the ion and photo spot type detection systems each alarming quickest to 3 and 8 of the tests, respectively. The persistence requirement of the data fusion smoke detection algorithm ensured that VS alarms triggered by the VID smoke detection algorithms were always slower than the VID alarms by 10 seconds. Because of the large dependence of the Fusion Machines on the VID systems to detect smoke, analysis comparing the VID system response times to the Fusion Machine response times is not informative.

During the nuisance tests, the SFA VID system performed the worst with 19 alarms, 10 of which occurred before any of the other detection systems. This performance was followed by the ionization detection system, which alarmed to 14 tests with 9 alarms activating before any of the other detection systems. The least amount of nuisance alarms was produced by the photoelectric detectors, which activated to 4 of the sources with 1 of the alarms activating before any other system. The Fusion Machines falsely alarmed to 9 and 7 nuisance sources for FM1 and FM2, respectively. The two fusion systems, however, never alarmed to a nuisance source first, due principally to the persistence requirements of the data fusion algorithms.

6.4 Performance Summary

This section summarizes the performance of the Volume Sensor prototypes and the component sensor systems. Performance is measured by the correct detections percentage for the event categories of flaming, smoldering, pipe rupture and nuisance sources, and the overall correct and incorrect detection percentages. The correct detections percentage was calculated by computing the ratio of the number of correctly detected events to the number of detection opportunities for each event type. For example, the number of pipe rupture detection opportunities was 16 for FM1, while the number of correct pipe rupture detections was 15, yielding a correct detection percentage of 94%. All numbers used in the correct and incorrect detection percentages are available on the attached disk in Appendix B. The overall correct detections percentage was calculated by computing the ratio of the number of correctly detected flaming, smoldering, and pipe rupture events to the number of detection opportunities for those event types and is a good approximation for a system's probability of event detection. The overall incorrect detections percentage was calculated by computing the ratio of the number of incorrect detections to the number of detection opportunities for all sources and is a good approximation for a system's probability of false alarm.

A preliminary performance summary of the Volume Sensor prototypes, listed as FM1 and FM2, and the SFA, SF, SBVS, LWVD, and ACST sensor systems for the event types of the current test series is presented in Table 24. Results for the VID systems were generated from the Fusion Machine logs and so represent events that the VID systems transmitted as opposed to events that they recorded. Presently, three alarms recorded by the SigniFire system, those for tests VS4-004, VS4-016, and VS4-054, are responsible for the differences in SigniFire entries between Tables 23 and 24. These alarms are being investigated, however, counting these tests as alarms for SF changes the nuisance and incorrect percentages listed in Table 24 to 63% and 19%, respectively, equal to those listed in Table 23.

The format of Table 24 is as follows: The first three rows of results list the correct detection percentages for flaming fires, smoldering fires, and pipe rupture events obtained from Tables 11, 12, 14, 15, 16 and 18. The fourth row lists correct detection percentages for nuisance source events from Tables 13 and 17. For the SFA, SF, and SBVS systems, the listed percentages represent the combined performance of all the system's detection algorithms. For the nuisance category, SBVS welding detections were considered correct detections for welding and torch cutting steel events. For the ACST system, the listed percentages represent the ACST pipe rupture algorithm, except for the nuisance category, where the listed percentage represents correctly detected nuisance alerts generated by the ACST nuisance algorithm. The fifth and sixth rows list the preliminary overall correct and incorrect detection percentages, respectively, for the Volume Sensor prototypes and the SFA, SF, SBVS, LWVD, and ACST sensor systems. The number of detection opportunities was adjusted across components to reflect that some components were not expected to detect certain event types. For example, the ACST pipe rupture algorithm was not expected to detect flaming or smoldering sources, so these tests were not included in its correct detections percentage calculation. However, any ACST pipe rupture alarms for flaming and smoldering tests were counted as incorrect detections and included in the incorrect detections percentage. Additionally, the SBVS calculations were adjusted for correctly detected welding and torch cutting steel events. The VID calculations did not include pipe rupture events for either the correct or incorrect detection percentages. False alarms that occurred during non-nuisance tests were included in the incorrect detection percentage calculations. Finally, tests where a false alarm occurred that was followed by subsequent correct event detection for an individual system are counted both as an incorrect detection, and as a correct detection for that system. All tests for which this occurred are discussed in section 5.3 above. The actual test counts used for all calculations pertaining to Table 24 are included in the alarm summaries spreadsheet on the attached disk.

Table 24 — Performance of the Percent Correct Classification of the Volume Sensor Prototypes, FM1 and FM2, and the Component Sensor Systems, SFA, SF, SBVS, LWVD, and ACST

Event Type	FM1	FM2	SFA	SF	SBVS	LWVD	ACST[1]
Flame	100%	100%	95%	95%	100%	100%	NA
Smoldering	100%	100%	100%	100%	46%	64%	NA
Pipe Rupture	94%	94%	NA[2]	NA[3]	NA	NA	94%
Nuisance	72%	78%	41%	69%	83%	66%	60%
Overall Correct	98.3%	98.3%	97.6%[2]	97.6%[3]	76%	81%	96%
Overall Incorrect	10%	8%	26%[4]	16%[4]	6%	13%	2%

[1] Entries refer to the ACST pipe rupture algorithm, except Nuisance, which refers to the ACST nuisance algorithms

[2] SFA alarmed for 75% of the pipe rupture sources, as transmitted to FM1

[3] SF alarmed for 13% of the pipe rupture sources, as transmitted to FM2

[4] Does not include events with pipe rupture sources

The event detection performance of the VS prototypes, FM1 and FM2, was roughly equivalent to that of their respective VID system components, SFA and SF, while the nuisance rejection performance of the VS prototypes was significantly better than the VID systems. Note that event detection includes pipe rupture sources for the VS prototypes, but not for the VID systems, which detected 75% and 13% of pipe rupture sources with their flame and smoke detection algorithms. The SBVS system demonstrated excellent flame detection and nuisance rejection, smoke detection was consistent with expectations. The LWVD system also gave excellent flame detection while smoke detection and nuisance rejection were consistent with expectations. The improved pipe rupture detection algorithm of the ACST system also performed very well. Finally, the new nuisance algorithms of the ACST system correctly identified over half the nuisance sources while compiling an incorrect detection percentage of only 10% (not shown).

Improved performance in the ability to detect smoldering and flaming sources was demonstrated by the VID systems when comparing the results obtained from VS3 to those obtained during VS4. Table 25 lists the number of alarms activated over the number of tests conducted for each of the common and relevant source types in each test series. The results are broken down by system and further, by VID system algorithm. Although a single VID system algorithm may not have always improved between the two test series, the systems as a whole demonstrated substantial improvements. The improved ability of the VID system smoke algorithms translated into improved Volume Sensor prototype performance, particularly for smoldering sources.

Table 25 — Comparison of Test Series VS4 and VS3 COTS System Detection Capabilities Measured in Number of Correct Classifications Over the Number of Tests for Each of Three Source Types; Flaming, Smoldering, and Nuisance

Test Series	**Ion**	**Photo**	**SFA Smoke**	**SFA Fire**	**SFA**	**SigniFire Offsite**	**SigniFire Smoke**	**SigniFire Fire**	**SigniFire**
Flaming Fires VS4	18/20	13/20	19/20	8/20	19/20	14/20	18/20	7/20	19/20
Flaming Fires VS3	17/17	17/17	7/17	9/17	10/17	8/17	13/17	5/17	13/17
Smoldering Fires VS4	18/22	21/22	22/22	1/22	22/22	2/22	22/22	1/22	22/22
Smoldering Fires VS3	19/19	19/19	5/19	4/19	6/19	1/19	12/19	1/19	12/19
Nuisance Sources VS4	18/32	28/32	21/32	19/32	13/32	27/32	27/32	24/32	20/32
Nuisance Sources VS3	12/24	20/24	22/24	22/24	22/24	20/24	23/24	21/24	18/24

Table 26 presents a comparison of the VS3 and VS4 results of the number of correct classifications over the number of tests from the two Fusion Machines as well as the SBVS, LWVD, and ACST components. The results are sorted by source and include all common sources, flaming, smoldering, nuisance, and pipe ruptures. The pipe rupture tests had the greatest Fusion Machine improvement due to the implementation of the data fusion pipe rupture algorithm for the VS4 Test Series. There was a decrease in the ability of the VS systems to discriminate nuisance sources due to the increased sensitivity of the VID systems improving smoke and fire detection and leading to more VID nuisance alarms. The LWVD, SBVS, and ACST components demonstrated equal or better ability to discriminate against nuisance sources. The new nuisance detection algorithms of the ACST component were able to identify 19 of the nuisance sources correctly as nuisance alerts, with the remaining 13 sources producing no alarms or alerts from the ACST component. Work is underway to incorporate this new capability of identifying nuisance sources into the data fusion algorithms. Overall, the Fusion Machines demonstrated improved fire detection performance due in part to the VID system improvements that increased the sensitivity of the two systems to smoke. Fire detection improved with the improved performance of the LWVD, SBVS, and VID systems as seen in Table 26.

Table 26 — Fusion Machine and SBVS, LWVD, and ACST Component Results from VS4 and VS3[1]

Test Series	FM1	FM2	LWVD	SBVS	ACST
Flaming Fires VS4	20/20	20/20	20/20	20/20	2/20
Flaming Fires VS3	16/17	16/17	14/17	15/17	0/17
Smoldering Fires VS4	22/22	22/22	13/22	10/22	1/22
Smoldering Fires VS3	8/18	13/19	10/19	7/19	0/19
Nuisance Sources VS4	23/32	25/32	23/32	26/32	13/32[2]
Nuisance Sources VS3	22/24	23/24	14/24	17/24	21/24
Pipe Rupture VS4	15/16	15/16	NA	NA	15/16
Pipe Rupture VS3	0/16	0/16	NA	NA	7/8

[1]Results are presented as number of alarms over number of tests for the two test series.
[2]13 out of 32 tests resulted in a DNA and the remaining tests resulted in a nuisance alert.

7.0 CONCLUSIONS

The Volume Sensor Test Series 4 successfully demonstrated the functionality and performance of the VS prototype system. Based on the test series and this initial analysis, the following conclusions are presented:

- The integration of the Volume Sensor components into a functioning prototype was a success. The components detected event conditions and communicated the alarms and alarm times to the Fusion Machines. In addition, both Volume Sensor prototypes outperformed the individual sensor system components in terms of event detection and nuisance rejection.

- The Fusion Machines incorporated data fusion algorithms that synthesized information from the sub-system components to improve performance, particularly in the areas nuisance source rejection.

- The Fusion Machine performed very well, demonstrating the ability to discriminate against nuisance sources and alarm to smoldering and flaming fires and pipe rupture sources.

- The ion and photo spot-type detectors correctly classified 56 and 88% of the nuisance sources, respectively. The VS prototypes FM1 and FM2 correctly classified 72 and 78% of the nuisance alarms, respectively.

- The ion and photo spot-type detectors correctly classified 90 and 65% of flaming fires, and 90 and 95% of smoldering fires, respectively. The VS prototypes FM1 and FM2 correctly classified 100 and 100 percent of flaming fires, and 100 and 100 percent of smoldering fires, respectively.

- Much of the improved nuisance rejection capability for the fusion systems was attributed to the speedy and accurate spectral based welding detection algorithm.

- Significant improvements in performance were made since the VS3 test series. Both VID systems demonstrated better sensitivity to smoke detection, which translated into improved Volume Sensor performance for fire and smoke detection. The inclusion of the data fusion pipe rupture algorithm provided excellent VS classification results for these events with nearly no false alarms. The improved data fusion nuisance rejection algorithm and increased persistence requirements for all data fusion algorithms reduced spurious false and incorrect alarms and kept the nuisance rejection performance of the VS prototypes at a much higher level than that of the commercial systems.

8.0 REFERENCES

1. Rose-Pehrsson, S.L., Owrutsky, J.C., Gottuk, D.T., Geiman, J.A., Williams, F.W., and Farley, J.P., "Phase I: FY01 Investigative Study for the Advanced Volume Sensor," NRL/MR/6110--03-8688, Naval Research Laboratory, Washington, DC, June 30, 2003.

2. Gottuk, D.T., Harrison, M.A., Scheffey, J.L., Rose-Pehrsson, S.L., Williams, F.W., and Farley, J.P., "An Initial Evaluation of Video-based Fire Detection Technologies," NRL/MR/6180--04-8737, Naval Research Laboratory, Washington, DC, January 9, 2004.

3. Carhart, H.W., Toomey, T.A., and Williams, F.W., "The ex-USS *Shadwell* Full-scale Fire Research and Test Ship," NRL Memorandum Report 6074, Naval Research Laboratory, Washington, DC, revised January 20, 1988, reissued 1992.

4. Wright, M.T., Gottuk, D.T., Darwin, R.T., Back, G.G., Peters, A., Farley, J.P., and Williams, F.W., "CVNX Fire Threat to Ordnance: Revised Test Plan for Test Series 2 - Magazine Detection System Response," NRL Ltr Rpt 6180/0159, Naval Research Laboratory, Washington, DC, April 7, 2003.

5. Gottuk, D.T., Harrison, M.A., Rose-Pehrsson, S.L., Owrutsky J.C., Williams, F.W., and Farley, J.P., "Video Image Detection (VID) Systems and Fire Detection Technologies: Preliminary Results from the Magazine Detection System Response Tests," NRL Ltr Rpt 6180/0262, Naval Research Laboratory, Washington, DC, July 21, 2003.

6. Gottuk, D.T., Harrison, M.A., Rose-Pehrsson, S.L., Owrutsky, J.C., Williams, F.W., and Farley, J.P., "Shipboard Evaluation of Fire Detection Technologies for Volume Sensor Development: Preliminary Results," NRL Ltr Rpt Ser 6180/0282, Naval Research Laboratory, Washington, DC, August 25, 2003.

7. Steinhurst, D.A., Minor, C.P., Owrutsky, J.C., Rose-Pehrsson, S.L., Gottuk, D.T., Williams, F.W., and Farley, J.P., "Long Wavelength Video-based Event Detection, Preliminary Results from the CVNX and VS1 Test Series, ex-USS *Shadwell*, April 7-25, 2003," NRL/MR-MM/6110--03-8733, Naval Research Laboratory, Washington, DC, December 31, 2003.

8. Owrutsky, J.C., Nelson, H.H., Steinhurst, D.A., and Williams, F.W., "Spectral-Based Component of the Volume Sensor Program," NRL/MR/6110—03-8694, Naval Research Laboratory, Washington, DC, July 30, 2003.

9. Steinhurst, D.A., Owrutsky, J.C., Rose-Pehrsson, S.L., Gottuk, D.T., Williams, F.W., and Farley, J.P., "Spectral-Based Volume Sensor Testbed, VS1 Test Series Results, ex-USS *Shadwell*, April 20-25, 2003," NRL Ltr Rpt 6110/075, Naval Research Laboratory, Washington, DC, June 27, 2003.

10. Steinhurst, D.A., and Nelson, H. H., "Direct Connection and IP-Based Data Acquisition Software for the Spectral-Based Component of the Volume Sensor Program," NRL Ltr Rpt 6110-053, Naval Research Laboratory, Washington, DC, April 20, 2004.

11. Wales, S.C., McCord, M.T., Schindall, J.A., Lynch J.A., Rose-Pehrsson, S.L. and Williams, F.W., "Acoustic Event Signatures for Damage Control: Fire and False Alarm Events," NRL/MR/7120, Naval Research Laboratory, Washington DC, in preparation.

12. Wales, S.C., McCord, M.T., Lynch, J.A., Rose-Pehrsson, S.L., and Williams, F.W., "Acoustic Event Signatures for Damage Control: Water Events and Shipboard Ambient Noise," NRL/MR/7120—04-8845, December 10, 2004.

13. Lynch, J.A., Gottuk, D.T., Rose-Pehrsson, S.L., Owrutsky, J.C., Steinhurst, D.A., Minor, C.P., Wales, S.C., Williams, F.W., and Farley, J.P., "Volume Sensor Development Test Series 2 – Lighting Conditions, Camera Settings, and Spectral and Acoustic Signatures," NRL/MR/6180--04-8843, Naval Research Laboratory, Washington, DC, November 24, 2004.

14. Lynch, J.A., Gottuk, D.T., Rose-Pehrsson, S.L., Owrutsky, J.C., Steinhurst, D.A., Minor, C.P., Wales, S.C., Williams, F.W., and Farley, J.P., "Test Report Volume Sensor Development Test Series 3 – Multi-Component Prototype Evaluation," NRL Ltr Rpt 6180/0353, Naval Research Laboratory, Washington, DC, September 20, 2004.

15. Military Handbook "Lighting on Naval Ships (Metric) DoD-HDBK-289 (SH), November 26, 1986.

16. James Nilsen, JJMA, personal communication March 17, 2000.

17. Minor, C.P., Steinhurst, D.A., Rose-Pehrsson, S. L., Owrutsky, J.C., Williams, F.W., and Gottuk, D.T., "Volume Sensor Prototype Development," NRL Ltr Rpt 6110/057, Naval Research Laboratory, Washington DC, April 2, 2004.

18. Minor, C.P., Steinhurst, D.A., Rose-Pehrsson, S. L., Owrutsky, J.C., and Williams, F.W., "Volume Sensor Communications Specification (VSCS)," NRL Ltr Rpt 6110/054, Naval Research Laboratory, Washington DC, April 2, 2004.

19. Steinhurst, D.A., Minor, C.P., Rose-Pehrsson, S. L., Owrutsky, J.C., and Williams, F.W., "Volume Sensor Data Methods of Operation Specification: Volume Sensor Data Fusion Command and Control (CnC) Program," NRL Ltr Rpt 6110/055, Naval Research Laboratory, Washington DC, April 2, 2004.

20. Steinhurst, D.A., Minor, C.P., Rose-Pehrsson, S. L., Owrutsky, J.C., and Williams, F.W., "Volume Sensor Data Methods of Operation Specification: Volume Sensor Human Interface (GUI) Program," NRL Ltr Rpt 6110/056, Naval Research Laboratory, Washington DC, April 2, 2004.

21. Minor, C.P., Steinhurst, D.A., Rose-Pehrsson, S. L., Owrutsky, J.C., and Williams, F.W., "Volume Sensor GUI/CnC Communications Specification: XML Packet Specification," NRL Ltr Rpt 6110/111, Naval Research Laboratory, Washington DC, September 14, 2004.

22. Steinhurst, D.A., Minor, C.P., Owrutsky, J.C., Rose-Pehrsson, S.L. and Williams, F.W., "NRL Volume Sensor: Long Wavelength Video Detection Component Prototype: Pre-Test Series 3 Progress Report" NRL Ltr Rpt 6110/110, Naval Research Laboratory, Washington, DC, August 24, 2004.

23. Steinhurst, D.A., Nelson, H.H., Owrutsky, J.C., Rose-Pehrsson, S.L. and Williams, F.W., "NRL Volume Sensor: Spectral-Based Volume Sensor Component Prototype: Pre-Test Series 3 Progress Report" NRL Ltr Rpt 6110/109, Naval Research Laboratory, Washington, DC, August 27, 2004.

APPENDIX A

ADJACENT SPACE NOZZLE LOCATION AND PARAMETERS

This appendix contains the adjacent space spray nozzle location as well as orientation.

Spray Fire	Nozzle Location Parameters			
	Starboard Nozzle			
	Height above deck (cm (in.))	Distance from exposed bulkhead (cm (in.))	Distance from nearest port bulkhead (cm (in.))	Spray pattern rotation from vertical (degrees)
3rd Deck Magazine	22.9 (9.0)	39.4 (15.5)	39.4 (15.5)	0

Spray Fire	Nozzle Location Parameters			
	Port Nozzle			
	Height above deck (cm (in.))	Distance from exposed bulkhead (cm (in.))	Distance from nearest port bulkhead (cm (in.))	Spray pattern rotation from vertical (degrees)
3rd Deck Magazine	22.9 (9.0)	39.4 (15.5)	100.3 (39.5)	0

APPENDIX B

MASTER TEST MATRIX

This appendix contains all of the recorded alarm times for the Fusion Machines and the alarm times of each component of the Volume Sensor (see attached disk).

Test	Brief Source Description	Source Type	Source Location	Date	Event Times (hh:mm:ss)			
					DAQ Start	Source Initiation	Source Transition	Source Terminated
VS4-028	Pipe ruptur	Pipe rupture	ft Stbrd Corn	10/21/04	9:48:00	9:52:00		9:55:00
VS4-031	Pipe ruptur	Pipe rupture	ft Stbrd Corn	10/21/04	11:02:00	11:11:02		11:14:00
VS4-037	Pipe ruptur	Pipe rupture	ft Stbrd Corn	10/21/04	15:00:00	15:04:00		15:08:30
VS4-045	Pipe ruptur	Pipe rupture	5	10/22/04	11:11:00	11:15:01		11:17:01
VS4-049	Pipe ruptur	Pipe rupture	5	10/25/04	8:14:02	8:18:00		8:23:10
VS4-051	Pipe ruptur	Pipe rupture	4	10/25/04	9:37:01	9:41:01		9:44:33
VS4-054	Pipe ruptur	Pipe rupture	4	10/25/04	10:40:02	10:44:01		10:48:23
VS4-057	Pipe ruptur	Pipe rupture	4	10/25/04	12:20:00	12:24:00		12:27:57
VS4-060	Pipe ruptur	Pipe rupture	4	10/25/04	13:40:00	13:44:00		13:49:00
VS4-062	Pipe ruptur	Pipe rupture	4	10/25/04	15:31:00	15:35:00		15:37:00
VS4-065	Pipe ruptur	Pipe rupture	4	10/26/04	9:00:00	9:04:00		9:06:00
VS4-071	Pipe ruptur	Pipe rupture	4	10/26/04	12:49:00	12:53:00		12:55:00
VS4-072	Pipe ruptur	Pipe rupture	4	10/26/04	13:04:00	13:08:00		13:10:00
VS4-079	Pipe ruptur	Pipe rupture	ft Stbrd Corn	10/27/04	8:01:00	8:05:01		8:07:00
VS4-087	Pipe ruptur	Pipe rupture	ft Stbrd Corn	10/27/04	13:25:00	13:29:01		13:31:01
VS4-093	Pipe ruptur	Pipe rupture	ft Stbrd Corn	10/28/04	8:07:00	8:25:00		8:30:00

Columns deleted:
No FM1 or FM2 flame alarms
No LWVD flame alarms
No SBVS smoke, flame, or welding alarms

Alarm Types:
F = flame
S = smoke
P = pipe rupture
N = nuisance
W = weld

Report Tables:

Test ID	**Source Description**	**FM1**			**FM2**		
		Alarm	**Response**	**Type**	**Alarm**	**Response**	**Type**
VS4-028	Pipe ruptur	9:53:05	65	P	9:53:05	65	P
VS4-054	Pipe ruptur	10:45:01	60	P	10:45:00	59	P
VS4-093	Pipe ruptur	8:27:52	172	S	DNA	DNA	DNA
VS4-031	Pipe ruptur	11:11:55	53	P	11:11:56	54	P
VS4-045	Pipe ruptur	11:17:16	135	P	11:17:16	135	P
VS4-049	Pipe ruptur	8:19:00	60	P	8:18:59	59	P
VS4-051	Pipe ruptur	9:42:05	64	P	9:42:05	64	P
VS4-062	Pipe ruptur	15:36:01	61	P	15:36:00	60	P
VS4-087	Pipe ruptur	13:30:10	69	P	13:30:10	69	P
VS4-065	Pipe ruptur	9:05:02	62	P	9:05:00	60	P
VS4-071	Pipe ruptur	12:54:03	63	P	12:54:02	62	P
VS4-072	Pipe ruptur	13:09:09	69	P	13:09:09	69	P
VS4-037	Pipe ruptur	15:04:54	54	P	15:04:55	55	P
VS4-057	Pipe ruptur	12:24:31	31	S	12:27:12	192	P

VS4-079	Pipe ruptur	8:05:56	55	P	8:05:56	55	P
VS4-060	Pipe ruptur	13:47:17	197	P	13:47:17	197	P

Number of Chances		16		16
Number of Alarms		16		15
Percentage Detected		100%		94%

Response	Mean	79	84
Times	STD	46.3	49.1
	Median	63	62

correcting for VS4-093 and VS4-057:

Mean	84
STD	49.0
Median	63

Stop DAQ	FM1 Smoke	FM1 Pipe Rupture	FM1 Alarm	FM1 Response	FM1 Type	FM2 Smoke	FM2 Pipe Rupture	FM2 Alarm
9:55:00		9:53:05	9:53:05	65	P		9:53:05	9:53:05
11:15:00	11:13:51	11:11:55	11:11:55	53	P		11:11:56	11:11:56
15:08:30	15:06:15	15:04:54	15:04:54	54	P	15:05:54	15:04:55	15:04:55
11:18:30		11:17:16	11:17:16	135	P		11:17:16	11:17:16
8:24:30		8:19:00	8:19:00	60	P		8:18:59	8:18:59
9:45:00	9:43:41	9:42:05	9:42:05	64	P		9:42:05	9:42:05
10:50:30	10:47:48	10:45:01	10:45:01	60	P		10:45:00	10:45:00
12:29:00	12:24:31	12:27:12	12:24:31	31	S		12:27:12	12:27:12
13:49:30	13:49:00	13:47:17	13:47:17	197	P		13:47:17	13:47:17
15:37:30	15:36:17	15:36:01	15:36:01	61	P		15:36:00	15:36:00
9:06:30		9:05:02	9:05:02	62	P		9:05:00	9:05:00
12:59:00		12:54:03	12:54:03	63	P		12:54:02	12:54:02
13:11:00		13:09:09	13:09:09	69	P		13:09:09	13:09:09
8:08:00	8:06:09	8:05:56	8:05:56	55	P	8:07:17	8:05:56	8:05:56
13:32:00		13:30:10	13:30:10	69	P		13:30:10	13:30:10
8:30:00	8:27:52		8:27:52	172	S			DNA

	FM1 Alarm	FM1 Response	FM2 Alarm
Number of Chances	16	16	16
Number of Alarms	16	16	15
Percentage Detected	100%	100%	94%

Test ID	Source Description	Fastcom SFA			AxonX SigniFire		
		Alarm	Response	Type	Alarm	Response	Type
VS4-028	Pipe ruptur	9:54:14	134	F	DNA	DNA	DNA
VS4-054	Pipe ruptur	10:45:00	59	F	DNA	DNA	DNA
VS4-093	Pipe ruptur	8:27:42	162	S	DNA	DNA	DNA
VS4-031	Pipe ruptur	11:13:41	159	S	DNA	DNA	DNA
VS4-045	Pipe ruptur	DNA	DNA	DNA	DNA	DNA	DNA
VS4-049	Pipe ruptur	DNA	DNA	DNA	DNA	DNA	DNA
VS4-051	Pipe ruptur	9:43:31	150	S	DNA	DNA	DNA
VS4-062	Pipe ruptur	15:36:07	67	S	DNA	DNA	DNA
VS4-087	Pipe ruptur	DNA	DNA	DNA	DNA	DNA	DNA
VS4-065	Pipe ruptur	9:04:42	42	F	DNA	DNA	DNA
VS4-071	Pipe ruptur	DNA	DNA	DNA	DNA	DNA	DNA
VS4-072	Pipe ruptur	13:09:02	62	F	DNA	DNA	DNA
VS4-037	Pipe ruptur	15:05:47	107	S	15:05:43	103	S
VS4-057	Pipe ruptur	12:24:20	20	S	DNA	DNA	DNA

VS4-079	Pipe ruptur	8:05:59	58	S	8:07:06	125	S
VS4-060	Pipe ruptur	13:48:50	290	S	DNA	DNA	DNA
		16			16		
		12			2		
		75%			13%		
			109			114	
			75.0			15.6	
			87			114	

FM2 Response	FM2 Type	SFA Smoke	SFA Flame	SFA Alarm	SFA Response	SFA Type	SF Smoke
65	P		9:54:14	9:54:14	134	F	
54	P	11:13:41		11:13:41	159	S	
55	P	15:05:47		15:05:47	107	S	15:05:43
135	P			DNA	DNA	DNA	
59	P			DNA	DNA	DNA	
64	P	9:43:31		9:43:31	150	S	
59	P	10:47:38	10:45:00	10:45:00	59	F	
192	P	12:24:20		12:24:20	20	S	
197	P	13:48:50		13:48:50	290	S	
60	P	15:36:07	15:36:35	15:36:07	67	S	
60	P		9:04:42	9:04:42	42	F	
62	P			DNA	DNA	DNA	
69	P		13:09:02	13:09:02	62	F	
55	P	8:05:59		8:05:59	58	S	8:07:06
69	P			DNA	DNA	DNA	
DNA	DNA	8:27:42		8:27:42	162	S	
16				16	16		
15				12	12		
94%				75%	75%		

Test ID	Source Description	LWVD	SBVS	ACST	
		Alarm	Alarm	Alarm	Response
VS4-028	Pipe rupture - 1m above dk, 4	DNA	DNA	9:52:55	55
VS4-054	Pipe rupture - 1m above dk, 4	DNA	DNA	10:44:50	49
VS4-093	Pipe rupture - Bete P24 nozz	DNA	DNA	DNA	DNA
VS4-031	Pipe rupture - gash 10" x 0.1	DNA	DNA	11:11:45	43
VS4-045	Pipe rupture - gash 10" x 0.1	DNA	DNA	11:17:06	125
VS4-049	Pipe rupture - gash 10" x 0.1	DNA	DNA	8:18:49	49
VS4-051	Pipe rupture - gash 10" x 0.1	DNA	DNA	9:41:55	54
VS4-062	Pipe rupture - gash 10" x 0.1	DNA	DNA	15:35:50	50
VS4-087	Pipe rupture - gash 10" x 0.1	DNA	DNA	13:29:59	58
VS4-065	Pipe rupture - gash 10" x 0.1	DNA	DNA	9:04:50	50
VS4-071	Pipe rupture - gash 10" x 0.1	DNA	DNA	12:53:51	51
VS4-072	Pipe rupture - gash 10" x 0.1	DNA	DNA	13:08:58	58
VS4-037	Pipe rupture - sprinkler nozzl	DNA	DNA	15:04:44	44
VS4-057	Pipe rupture - sprinkler nozzl	DNA	DNA	12:24:42	42

VS4-079	Pipe rupture - sprinkler nozzl	DNA	DNA	8:05:46	45
VS4-060	Pipe rupture - water mist noz	DNA	DNA	13:47:07	187
		16	16	16	
		0	0	15	
		0%	0%	94%	
					64
					39.5
					50

SF Flame	SF Alarm	SF Response	SF Type	ACST Pipe Rupture	ACST Nuisance	ACST Alarm	ACST Response	ACST Type
	DNA	DNA	DNA	9:52:55		9:52:55	55	P
	DNA	DNA	DNA	11:11:45		11:11:45	43	P
	15:05:43	103	S	15:04:44	15:05:44	15:04:44	44	P
	DNA	DNA	DNA	11:17:06		11:17:06	125	P
	DNA	DNA	DNA	8:18:49	8:20:29	8:18:49	49	P
	DNA	DNA	DNA	9:41:55		9:41:55	54	P
	DNA	DNA	DNA	10:44:50	10:46:24	10:44:50	49	P
	DNA	DNA	DNA	12:24:42	12:25:12	12:24:42	42	P
	DNA	DNA	DNA	13:47:07	13:46:38	13:46:38	158	N
	DNA	DNA	DNA	15:35:50		15:35:50	50	P
	DNA	DNA	DNA	9:04:50		9:04:50	50	P
	DNA	DNA	DNA	12:53:51	12:57:08	12:53:51	51	P
	DNA	DNA	DNA	13:08:58		13:08:58	58	P
	8:07:06	125	S	8:05:46		8:05:46	45	P
	DNA	DNA	DNA	13:29:59		13:29:59	58	P
	DNA	DNA	DNA			DNA	DNA	DNA
	16	16				16	16	
	2	2				15	15	
	13%	13%				94%	94%	

Type
P
P
DNA
P
P
P
P
P
P
P
P
P
P
P

P
P

APPENDIX C

RECORDED CHANGES OR MOVEMENT OF SOURCES

This appendix contains the time history of various sources tested. Many of the sources involve people moving throughout the test space. These movements were recorded along with changes to the source elevation, voltage increases, and addition of material. These changes to the sources as well as others are recorded within this appendix (see attached disk).

Test Number	Brief test description	Timeline and notes
VS4-01	Flaming Cardboard boxes	Four cardboard boxes were filled with polystyrene pellets and set on the deck at location 2. Ventilation was set to 5 ACH. ~255 sec after DAQ start boxes were ignited with lighter.
VS4-02	Welding	Welding was conducted at Location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start welding was initiated. ~80 sec after start of welding first rod completed ~160 sec after start of welding second rod completed ~180 sec after start of welding third rod started. ~250 sec after start of welding third rod completed ~255 sec after start of welding forth rod started. ~345 sec after start of welding fifth rod started. ~420 sec after start of welding fifth rod completed, and welding secured.
VS4-03	Smoldering Mattress and Bedding	A 1ft by 1ft section of mattress with bedding was placed on the deck at location 2. Ventilation was set to 5 ACH. ~240 sec after DAQ start source was initiated and heater cartridge was supplied with 85 VAC. ~560 sec after initiation of the source light smoke was visible in the OH. ~630 sec after source start someone stepped into the compartment momentarily through the fwd door. ~15 minutes after source initiation variac voltage increased to 100 VAC and heater moved to virgin material. ~24 minutes and 5 seconds after source initiation the fire was secured.
VS4-04	VHF Radio	A VHF WIFCOM radio was used in the test compartment at locations 5, 4, and 2. Ventilation was on and set to 5 ACH. ~240 sec after DAQ start communication transmission started at location 5. ~30 seconds after first transmission a second transmission at location 4. ~ 60 seconds after first transmission a third transmission at location 2. ~90 seconds after first transmission test secured. Note: Transmission follows exact script from VS3.
VS4-05	Torch cutting steel	The oxyacetylene torch cutting was conducted on the deck at Location 4. Ventilation was set to 5 ACH. ~240 seconds after DAQ start torch was lit ~20 sec after the torch was lit cutting was initiated. ~55 sec after the torch was lit cutting stopped then restarted cutting. ~90 sec after the torch was lit cutting stopped then restarted cutting

		~115 sec after the torch was lit cutting stopped then restarted cutting. ~145 sec after the torch was lit cutting stopped then restarted cutting. ~185 sec after the torch was lit cutting stopped then restarted cutting. ~205 sec after the torch was lit cutting stopped then restarted cutting. ~240 sec after the torch was lit cutting stopped then restarted cutting ~260 sec after the torch was lit cutting stopped then restarted cutting. ~290 sec after the torch was lit cutting stopped then restarted cutting ~320 sec after the torch was lit cutting stopped then restarted cutting. ~365 seconds after torch was lit torch was secured.
VS4-06	Flaming Trash Can	The trash can was placed on the deck. Ventilation was set to 5 ACH. ~240 sec after DAQ start the fire was started. ~60 sec after ignition flame height was ~1 ft above trash can. ~120 sec after ignition plastic bag dripping and melting falling to deck. ~ 460 sec after ignition the fire was extinguished.
VS4-07	Smoldering Cable bundle	A cable bundle was placed at location 2 in the metal flange on the fwd bulkhead. Ventilation was set to 5 ACH. ~240 sec after DAQ start source was initiated by energizing heater cartridge to 84VAC ~120 sec after source initiation smoke visible in the fwd port (bay 2P) OH. ~ 25 minutes after source initiation voltage increased to 100 VAC. ~ 27 minutes after source initiation a steady stream of smoke from the cable bundle can be seen. ~35 minutes after start of source voltage raised to 120 VAC. ~ 35 minutes and 20 seconds after source initiation source transitions to flaming fire. ~40 minutes after start of source voltage and source was secured.
VS4-08	Welding (140A)	Welding was conducted at Location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start welding was initiated. ~55 sec after start of welding first rod completed ~60 sec after start of welding second rod started. ~115 sec after start of welding second rod completed ~120 sec after start of welding third rod started.

		~170 sec after start of welding third rod completed ~180 sec after start of welding forth rod started. ~230 sec after start of welding forth rod completed ~238 sec after start of welding fifth rod started. ~285 sec after start of welding fifth rod completed ~290 sec after start of welding, welding secured.
VS4-09	Flaming Shipping Supplies	A 2 ft by 1 ft section of wood pallet with 3 polyethylene bottles wrapped in plastic wrap and ignited by a 2 in by 2 in IPA pool fire was placed at location 2. Ventilation was on and set to 5 ACH. ~265 sec after DAQ start IPA pool fire was ignited and placed in the middle of the wood pallet impinging on the one of the wood planks and the plastic bottles. ~60 sec after ignition flame went out and had to be re-ignited.
VS4-10	Waving Materials	A white cotton rag was waved, shaken, and folded by a person moving in the compartment and stopping in front of each camera for a minimum of 30 sec. The ventilation was on at 5 ACH. ~240 sec after DAQ start material waving and folding at location 5 ~95 sec after start of waving process done over again at location 5 ~150 sec after start of waving process moved to location 4. ~215 sec after start of waving process re-started waving ect at location 4 ~305 sec after start of waving process moved to location 3 ~335 sec after start of waving process folded rag. ~395 sec after start of waving process exited space ~455 sec after start of waving process moved to center of compartment with rag covering safety back. ~510 sec after start of waving process started moving back and forth at center of compartment. ~570 sec after start of waving process secured test.
VS4-11	Smoldering Laundry	The Laundry (six cotton rags measuring 14in by 14in., 7in by 7in. folded) was placed on the deck at Location 2. A heater cartridge was placed in the middle of the rags and initially power to 97 VAC. Ventilation was set to 5 ACH. ~240 sec after DAQ start cartridge heater started. (97 VAC) ~120 sec after heater started a steady stream of smoke visible from source fwd and aft edges of the pile ~220 sec after heater started smoke haze visible from camera at VS location 3. ~600 sec after heater started source power was secured. ~620 sec after heater started source fire secured
VS4-12	Spilling	A bin of metal bolts spilled on the deck from approximately

	Metal bolts	waist height. Spill rate varied from slow (~5 bolts per seconds) to fast (~100 bolts per second) Ventilation was running at 5 ACH. ~240 sec after DAQ start bolts dropped slowly at location 4 ~70 sec after first drop bolts dropped fast at location 4 ~180 sec after first drop bolts dropped slowly at location 1 ~250 sec after first drop bolts dropped fast at location 1 ~360 sec after first drop hammering on cabinet at location 4 ~455 sec after first drop scraping pipe on deck
VS4-13	AM/FM Radio	A Radio and tape player was positioned on a 55-gal drum at location 4. The ventilation was on and set to 5 ACH. ~ 240 sec after DAQ start radio was turned on. Played classical with static. ~140 sec after radio started changed station to rock with static, radio beeps with changing station. ~260 sec after radio started station was changed (beeps while changing) ~280 sec after radio started stops on a rock station. ~345 sec after radio started switched from radio to cassette (Heavy Metal) ~ 500 sec after radio started music secured.
VS4-14	Grinding steel	A steel plate was painted and placed on the deck at location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start grinding was initiated. ~240 sec after start of source grinding was stopped momentarily and safety repositioned with back to port. ~260 sec after start of source grinding started again. ~480 sec after source start the source was secured.
VS4-15	IPA spill fire with trash bag	250 ml of IPA was poured on the deck forming a pool. A trash bag was placed by the pool in location 2. Ventilation was on and set to 5 ACH and the LPES was on. ~ 240 sec after DAQ start pool was ignited with a butane lighter. ~ 60 sec after ignition the trash bag was involved. ~160 sec after ignition safety secured fire.
VS4-16	Diesel Engine exhaust	Engine exhaust was pumped into the room from WTD 3-29-1 from the forklift aboard the Shadwell through a pipe into the compartment. Ventilation was set to 5 ACH. ~ 240 seconds after DAQ start forklift started. ~240 seconds after start of forklift engine revved. ~300 sec after start of forklift engine returned to idle. ~390 sec after start of forklift engine revved. ~420 sec after start of forklift engine returned to idle. ~540 sec after start of forklift fork lift secured.
VS4-17	Smoldering Oily rags	Five 14" by 14" rags were soaked with ~30 ml of 10W30 motor oil each and placed in a trash can with a heater cartridge at

		location 2. Ventilation was set to 5 ACH. ~240 sec after DAQ start heater was energized to 85 VAC. ~105 sec after source start light smoke visible from network camera. ~510 sec after start of source light haze smoke in the OH visible on camera at location VS3. ~25 minutes after source start the source power was secured. ~25 minutes and 50 sec after source start the source was secured.
VS4-18	Flaming Cardboard boxes	Cardboard boxes were filled with polystyrene pellets and set on the deck at location 3. Ventilation was set to 5 ACH. ~250 sec after DAQ start boxes were ignited with lighter. ~50 sec after ignition flame height 6 to 8 inches above boxes. ~110 sec after ignition flame height 2 ft above boxes. The flame height is at the edge view of camera and nightshot at VS location 2. ~240 sec after ignition black smoke throughout compartment. ~325 sec after ignition safety secures fire.
VS4-19	TV	A TV was placed on a 55-gal drum at location 4. Ventilation was on and set to 5 ACH. ~ 240 sec after DAQ start TV was turned on. ~25 sec after source turned on volume set moderate ~170 sec after source turned on the TV channels were changed. ~295 sec after source turned on the TV was secured.
VS4-20	TV with VCR	A TV and VCR were placed on a 55-gal drum at location 4. Ventilation was on and set to 5 ACH. ~ 240 sec after DAQ start TV and VCR were turned on. ~10 sec after source turned on VCR was playing video with volume set half-way ~240 sec after source turned on the TV and VCR were moved to the top of a cabinet near location 4. ~370 sec after source turned on the magazine lights were turned off. ~540 sec after source turned on the lights were turned back on. ~555 sec after source turned on TV and VCR were secured.
VS4-21	Smoldering Mattress and Bedding	A 1ft by 1ft section of mattress with bedding was placed on the deck at location 3. Ventilation was set to 5 ACH. ~240 sec after DAQ start source was initiated and heater cartridge was supplied with 85 VAC. ~ 120 sec after initiation smoke coming from the mattress was visible on the source camera. ~360 sec after initiation of the source light smoke was visible from a camera at VS location 2. ~15 minutes after source initiation variac voltage increased to 100 VAC and heater moved to virgin material. ~19 minutes and 40 seconds after source initiation source

		transitioned to flaming fire. ~21 minutes and 40 seconds after source initiation the power was secured. ~22 minutes and 10 seconds after source initiation the fire was secured.
VS4-22	Flaming Trash Can	The trash can was placed on the deck at Location 3. Ventilation was set to 5 ACH. ~240 sec after DAQ start the fire was started. ~240 sec after ignition flame visible from CCTV and nightshot cameras at VS location 2. ~ 14 minutes and 45 sec after ignition the fire was extinguished.
VS4-23	Smoldering Cable bundle	A cable bundle was placed at location 3 in the OH grid. Ventilation was set to 5 ACH. ~240 sec after DAQ start source was initiated by energizing heater cartridge to 84VAC ~120 sec after source initiation smoke visible from cable from source camera. ~180 sec after source initiation smoke visible from cable from cameras at VS location 2. ~ 25 minutes after source initiation voltage increased to 100 VAC. ~32 minutes after start of source voltage and source was secured.
VS4-24	Toasting	Four sliced of white bread were toasted in a 1500 W toaster at the darkest setting for two cycles. Toaster was set on top of a 55-gal drum at location 4. Ventilation was off during test. ~240 sec after DAQ start toasting started. ~180 sec after toasting started first cycle ended and second cycle began. ~300 sec after toasting started second cycle ended and toast was removed and replaced with new bread. (puff of smoke when toaster popped) ~480 sec after toasting started second set of bread popped and a second cycle was started. ~590 sec after toasting started second cycle of second set popped ~690 sec after toasting started test was secured.
VS4-25	Torch cutting steel	The oxyacetylene torch cutting was conducted on the deck at Location 3. Ventilation was set to 5 ACH. ~240 seconds after DAQ start torch was lit ~30 sec after the torch was lit cutting was initiated. ~130 sec after torch was lit completed cutting one piece and restarted cutting. ~180 sec after torch cutting began (10 sec after torch went out) cutting resumed. ~345 seconds after torch was lit torch was secured.

VS4-26	Flaming Cardboard boxes	Cardboard boxes were filled with polystyrene pellets and set on the deck at location 5. Ventilation was set to 5 ACH. ~240 sec after DAQ start boxes were ignited with lighter and a sustained flame was created. ~230 sec after ignition of boxes black smoke produced. ~300 sec after ignition black smoke throughout compartment. ~480 sec after ignition fire is barely flickering – small flame. ~540 sec after ignition safety secures fire.
VS4-27	Flaming Shipping Supplies	A 2 ft by 1 ft section of wood pallet with 3 polyethylene bottles wrapped in plastic wrap and ignited by a 2 in by 2 in IPA pool fire was placed at location 3. ~240 sec after DAQ start IPA pool fire was ignited and placed in the middle of the wood pallet impinging on the one of the wood planks and the plastic bottles. ~13 minutes after ignition fire had reduced down started to produce smoke. ~ 14 minutes and 30 seconds after ignition the fire was secured
VS4-28	Pipe Rupture	A 1" pipe, at location 9, 1 m above the deck (no nozzle) was supplied with water. The mechanical ventilation was set to 5 ACH. The pipe was supplied with water at 40 psi ~240 sec after DAQ start pipe rupture was started (38 psi). ~180 sec after rupture start rupture secured.
VS4-29	People working / Cleaning in the Space	Three people were cleaning and mopping and replacing a pipe throughout the space. Ventilation was on and set to 5 ACH. ~240 sec after DAQ start cleaning and removing rupture pipe began. ~8 minutes after start of cleaning the test was secured.
VS4-30	Smoldering Laundry	The Laundry was placed on the deck at Location 3. Ventilation was set to 5 ACH. ~240 sec after DAQ start cartridge heater started. (97 VAC) ~85 sec after heater started smoke visible from source ~120 sec after heater started smoke haze visible from camera at VS location 2. ~13 minutes after heater started source transitioned to flaming fire (small flame) ~15 minutes after heater started source flame appeared to be out. ~16 minutes after heater started source power was secured. ~17 minutes after heater started source fire secured
VS4-31	Pipe Rupture (gash)	A 1" pipe with a 10" by 1/8" gash was placed at location 9 facing STBD. The mechanical ventilation was set to 5 ACH. ~540 sec after start of DAQ rupture was started (38-40 psi). Sprayed toward STBD bulkhead lower corner. ~180 sec after start of rupture, rupture secured.
VS4-32	IPA spill fire with	250 ml of IPA was poured on the deck forming a pool. A trash bag was placed by the pool in location 3. Ventilation was on

	trash bag	and set to 5 ACH. ~ 250 sec after DAQ start pool was ignited with a butane lighter. ~ 50 sec after ignition visible flame view from CCTV and nightshot camera at VS location 2. ~200 sec after ignition the IPA spill fire was out. ~290 sec after ignition safety secured fire.
VS4-33	Smoldering Oily rags	Five 14" by 14" rags were soaked with ~1oz of oil each and placed in a trash can with a heater cartridge at location 3. Ventilation was set to 5 ACH. ~230 sec after DAQ start heater was energized to 85 VAC. ~190 sec after source start light smoke visible from camera at VS location 2. ~430 sec after start of source increased smoke production visible. ~610 sec after start of source light smoke throughout the compartment. ~15 minutes and 10 sec after source start the source was secured.
VS4-34	Heat gun, space heater, and Fan	A heat gun, space heater and fan were used in the compartment at locations 5, 4, and 1 as nuisance sources. The ventilation was off. ~240 sec after DAQ start heat gun was started at location 5 and run for 1 minute. ~70 sec after start of heat gun at location 5 the heat gun was started at location 4 and run for 1 minute ~150 sec after start of heat gun at location 5 heat gun was started at location 1 for 1 minute. ~210 sec after start of heat gun at location 5 heat gun was secured. ~270 sec after start of heat gun at location 5 space heater started at location 4 ~410 sec after start of heat gun at location 5 space heater visible on IR camera 1. ~570 sec after start of heat gun at location 5 fan started (low speed oscillation) Fan blocked lower half view of the space heater – camera 1) Fan was blowing toward the heater – STBD ~770 sec after start of heat gun at location 5 Fan placed on high speed ~890 Sec after start of heat gun at location 5 all sources secured.
VS4-35	Grinding steel	A steel plate was painted and placed on the deck at location 3. Ventilation was set to 5 ACH. ~240 sec after DAQ start grinding was initiated. ~100 sec after start of source grinding was stopped momentarily. ~110 sec after start of source grinding started again.

		~360 sec after source start the source was secured.
VS4-36	Smoldering Mattress and Bedding	A 1ft by 1ft section of mattress with bedding was placed on the deck at location 5. Ventilation was set to 5 ACH. ~240 sec after DAQ start source was initiated and heater cartridge was supplied with 85 VAC. ~ 90 sec after initiation smoke coming from the mattress was visible on the source camera. ~480 sec after initiation of the source light smoke was visible from a camera at VS location 3. ~15 minutes after source initiation variac voltage increased to 100 VAC and heater moved to virgin material. ~17 minutes after source initiation source transitioned to flaming fire and black smoke was produced. ~19 minutes after source initiation flame size decreased ~19 minutes and 30 seconds minutes after source initiation, the test was secured.
VS4-37	Pipe Rupture	A sprinkler head (TF29-180 FC28) was attached to a 1" pipe, at location 9, 1 m above the deck. The mechanical ventilation was set to 5 ACH. The pipe was supplied with water at 40 psi ~240 sec after DAQ start pipe rupture was started (42 psi). ~30 sec after rupture water was secured. ~90 sec after rupture water was activated again. ~270 sec after rupture start rupture secured.
VS4-38	Flaming Trash Can	The trash can was placed on the deck at Location 5. Ventilation was set to 5 ACH. ~240 sec after DAQ start the fire was started. ~ 420 sec after ignition the fire was extinguished, white smoke produced.
VS4-39	Smoldering Cable bundle	A cable bundle was placed at location 5 in the OH. Ventilation was set to 5 ACH. ~240 sec after DAQ start source was initiated by energizing heater cartridge to 84VAC? Actually 100 VAC ~60 sec after source start the variac was initially set to 100 VAC briefly but was then returned to 84 VAC. ~150 sec after source initiation smoke visible from cable. ~18 minutes after start of source there appeared to be light smoke movement across the compartment from CCTV VS location 3. ~ 25 minutes after source initiation voltage increased to 100 VAC. ~35 minutes after start of source voltage and source was secured.
VS4-40	Gas Release	A N2 tank cylinder with ¼ in copper tubing pressurized to 125 psi was run to the deck by the starboard bulkhead. An air hose was also placed in the compartment. ~240 sec after start of DAQ gas was released at 125 psi.

		~120 sec after release gas was secured and reduced to 50 psi. ~300 sec after initial release gas was released at 50 psi. ~420 sec after initial release second discharge was secured for final time. ~540 sec after initial release air hose was tested out side of compartment. ~600 sec after initial release air hose was opened and run continuously (85 psi static) ~720 sec after initial release air hose was secured.
VS4-41	Smoldering Laundry	The Laundry was placed on the deck at Location 5. Ventilation was set to 5 ACH. ~240 sec after DAQ start cartridge heater started. (97 VAC) ~100 sec after heater started smoke visible from source ~195 sec after heater started smoke haze visible at 5ft level and visible from camera 6 (VS3). ~500 sec after heater started source was secured.
VS4-42	Gas Release	A N2 tank cylinder with ¼ in copper tubing pressurized to 50 psi then increased to 125 psi was run to the OH in location 4. ~240 sec after start of DAQ gas was released at 50 psi. ~240 after release gas was secured. ~300 sec after initial release gas was released at 125 psi. ~420 sec after initial release second discharge was secured for final time.
VS4-43	Flaming Shipping Supplies	A 2 ft by 1 ft section of wood pallet with 3 polyethylene bottles wrapped in plastic wrap and ignited by a 2 in by 2 in IPA pool fire was placed at location 5. ~270 sec after DAQ start IPA pool fire was ignited and placed in the middle of the wood pallet impinging on the one of the wood planks and the plastic bottles. ~30 sec after ignition IPA went out and was re-ignited ~570 sec after ignition majority of the flame is burning on the aft port corner side of the pallet. ~26 minutes after ignition fire had reduced down. ~ 37 minutes after ignition the fire was secured
VS4-44	IPA spill fire with trash bag	250 ml of IPA was poured on the deck forming a pool. A trash bag was placed by the pool in location 5. Ventilation was on and set to 5 ACH. ~ 9 minutes after DAQ start pool was ignited with a butane lighter.(extended background time to reset General Atomics sensors) ~ 60 sec after ignition the trash bag was involved. ~330 sec after ignition the IPA spill fire was out. ~395 sec after ignition safety secured fire.
VS4-45	Pipe Rupture (gash)	A 1" pipe with a 10" by 1/8" gash was placed at location 5 facing Aft. The mechanical ventilation was set to 5 ACH. ~240 sec after start of DAQ rupture was started (39-41 psi).

		~180 sec after start of rupture, rupture secured.
VS4-46	Smoldering Oily rags	Five 14" by 14" rags were soaked with ~1oz of oil each and placed in a trash can with a heater cartridge at location 5. Ventilation was set to 5 ACH. ~240 sec after DAQ start heater was energized to 85 VAC. ~420 sec after source start safety reports light smoke visible, smoke is not visible from any cameras. ~600 sec after start of source smoke visible from CCTV at VS location 3. ~21 minutes and 20 sec after source start the source was secured.
VS4-47	Gas Release	A N2 tank cylinder with ¼ in copper tubing pressurized to 50 psi then increased to 125 psi. Also a 1/16 in fitting connected to the ¼ in copper tube pressurized to 50 psi and 125 psi. was run to the OH in location 4. ~240 sec after start of DAQ gas was released at 50 psi. ~240 after release gas was secured. ~300 sec after initial release gas was released at 125 psi. ~420 sec after initial release second discharge was secured. ~600 sec after initial release gas was release though a 1/16 inch fitting at 50 psi ~720 sec after initial release gas was secured ~ 900 sec after initial release pressure was raised to 125 psi and released though the 1/16 inch fitting. ~1020 sec after initial release gas was secured for final time.
VS4-48	Adjacent Space Fire	A heptane spray fire from two BETTE fog nozzles (FF033 @25 psi) located in the radio transmitter room adjacent to the 3rd deck magazine impinged on the common bulkhead. Ventilation was set to 5 ACH. ~240 sec after DAQ start the tell tale was lit. ~265 sec after DAQ start the adjacent space fire was initiated. The nozzles were pressurized with heptane at 25 psi. ~320 sec after start of flow pressure was increased to 40 psi. ~885 sec after start of flow fuel secured.
VS4-49	Pipe Rupture (gash)	A 1" pipe with a 10" by 1/8" gash was placed at location 5 facing the forward bulkhead. The mechanical ventilation was set to 5 ACH. ~240 sec after start of DAQ rupture was started (39-40 psi). ~130 sec after start of rupture pressure increased to 100 psi. ~200 sec after start of rupture pressure at 99-100 psi ~310 sec after start of rupture, rupture secured.
VS4-50	Flaming Shipping Supplies	A 2 ft by 1 ft section of wood pallet with 3 polyethylene bottles wrapped in plastic wrap and ignited by a 2 in by 2 in IPA pool fire was placed at location 4. ~240 sec after DAQ start IPA pool fire was ignited and placed in the middle of the wood pallet impinging on the one of the

		wood planks and the plastic bottles. ~120 sec after ignition plastic was melting and dripping to the deck ~19 minutes after ignition fire was extinguished and white smoke was generated.
VS4-51	Pipe Rupture (gash)	A 1" pipe with a 10" by 1/8" gash was placed at location 4 facing the port aft corner. The mechanical ventilation was set to 5 ACH. The pipe was supplied with water at 40 psi and 100 psi. ~240 sec after DAQ start pipe rupture was started (40-41 psi). ~120 sec after rupture pressure was increased to 100 psi. ~170 sec after rupture pressure was at 98-100 psi ~210 sec after rupture start rupture secured.
VS4-52	People working / Cleaning in the Space	Two people were cleaning and mopping though out the space. Ventilation was on and set to 5 ACH. ~10 sec after DAQ start cleaning and calibration began. ~10 minutes after start of cleaning the test was secured.
VS4-53	IPA spill fire with trash bag	250 ml of IPA was poured on the deck forming a pool. A trash bag was placed by the pool in location 4. Ventilation was on and set to 5 ACH. ~ 13 minutes after DAQ start pool was ignited with a butane lighter.(extended background time to reset General Atomics sensors) ~ 60 sec after ignition the trash bag was involved. ~180 sec after ignition the IPA spill fire was out. ~360 sec after ignition safety secured fire.
VS4-54	Pipe Rupture	A 1" pipe, at location 4, 1 m above the deck had a direct discharge (no nozzles). The mechanical ventilation was set to 5 ACH. The pipe was supplied with water at 40 psi and 100 psi. ~240 sec after DAQ start pipe rupture was started (36-42 psi). ~120 sec after rupture pressure was increased to 100 psi. ~160 sec after rupture pressure was at 100 psi ~260 sec after rupture start rupture secured.
VS4-55	People working / Cleaning in the Space	Two people were cleaning and mopping though out the space while one person calibrated the ODM's in the OH.. Ventilation was on and set to 5 ACH. ~240 sec after DAQ start cleaning and calibration began. ~11 minutes after start of cleaning and calibration the test was secured.
VS4-56	Grinding steel	A steel plate was painted and placed on the deck at location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start grinding was initiated with a 4 inch grinder. Note: did not generate a lot of sparks. ~130 sec after start of source more sparks were generated. ~210 sec after start of source change grinder to create more sparks. ~235 sec after start of source grinding started with new grinder.

		~475 sec after source start (original grinder) source secured.
VS4-57	Pipe Rupture	A nozzle (TF29-180-28) was attached to a 1" pipe, at location 4, 1 m above the deck. The mechanical ventilation was set to 5 ACH. The head was supplied with water at 40 psi. ~240 sec after DAQ start pipe rupture was started. ~120 to 180 sec after rupture pressure increased to 100 psi. ~240 sec after rupture start rupture secured.
VS4-58	Flaming Cardboard boxes	Two Cardboard boxes were filled with polystyrene pellets and set on an elevated surface (3'9") at location 7. Ventilation was set to 5 ACH. ~280 sec after DAQ start boxes were ignited with lighter and a sustained flame was created. ~210 sec after ignition of boxes the fire involved 40% of the boxes ~230 sec after ignition aft box fell from elevated stand. ~320 sec after ignition boxes fully involved ~545 sec after ignition flame out then re-ignited ~580 sec after ignition safety secures fire.
VS4-59	Gas Release	Gas was released from an SCBA at location 4. Ventilation was on and set to 5 ACH. ~240 sec after DAQ start discharge from SCBA. ~90 sec after discharge bell ringing on SCBA because of low air. ~105 sec after start of SCBA discharge test secured.
VS4-60	Pipe Rupture	A nozzle (BETE P-80) was attached to a 1" pipe, at location 4, 1 m above the deck. The mechanical ventilation was set to 5 ACH. The head was supplied with water at 40 psi. ~240 sec after DAQ start pipe rupture was started. ~135 sec after rupture pressure increased ~165 sec after rupture pressure finished increasing to 108 psi. ~300 sec after rupture start rupture secured.
VS4-61	Smoldering Cable bundle	A cable bundle was placed at location 3 on the deck. Ventilation was set to 5 ACH. ~240 sec after DAQ start source was initiated by energizing heater cartridge to 84VAC ~450 sec after source initiation smoke visible from cable. ~ 25 minutes after source initiation voltage increased to 100 VAC. ~ 26 minutes after source initiation noticeable increase in smoke production. ~37 minutes after start of source cable bundle voltage increased to 120 VAC. ~45 minutes after start of source voltage and source was secured.
VS4-62	Pipe Rupture	A 1" pipe with a 10" by 1/8" gash was placed at location 4 facing boxes. The mechanical ventilation was set to 5 ACH.

	(gash)	~240 sec after start of DAQ rupture was started. ~360 sec after DAQ start rupture secured.
VS4-63	Adjacent Space Fire	A heptane spray fire located in the radio transmitter room adjacent to the 3rd deck magazine impinged on the common bulkhead. Ventilation was set to 5 ACH. ~300 sec after DAQ start the tell tale was lit. ~360 sec after DAQ start the adjacent space fire was initiated. The nozzles were pressurized with heptane at 40 psi. The starboard nozzle was clogged. ~660 sec after start of flow pressure was increased to 60 psi. ~720 sec after start of flow pressure reaches 60 psi and a half pattern on starboard nozzle. ~820 sec after start of flow pressure increased to 80 psi. ~855 sec after start of flow pressure reaches 80 psi ~1155 sec after start of flow fuel secured.
VS4-64	Diesel Engine exhaust	Engine exhaust was pumped into the room from the forklift aboard the Shadwell through a pipe into the compartment. Ventilation was set to 5 ACH. ~ 260 seconds after DAQ start forklift started. ~25 seconds after start of forklift engine rev up and remained at a high RPM, puff of smoke visible at beginning of rev up. ~90 sec after start of forklift engine returned to idle. ~110 sec after start of forklift engine rev up and down (quick revs) with puffs of smoke after each rev. ~150 sec after start of forklift engine returned to idle. ~190 sec after start of forklift engine shut down. ~210 sec after start of forklift engine started again and revved. ~270 sec after start of forklift engine revved and held at moderate RPM. ~350 sec after start of forklift additional RPM and help steady. ~430 sec after start of forklift engine back to idle ~445 sec after start of forklift fork lift secured safety removes pipe. ~490 sec after start of forklift fork lift started again. ~505 sec after start of forklift fork lift clear of test space
VS4-65	Pipe Rupture (gash)	A 1" pipe with a 10" by 1/8" gash was placed at location 4 facing boxes. The mechanical ventilation was set to 5 ACH. ~240 sec after start of DAQ rupture was started. ~360 sec after DAQ start rupture secured.
VS4-66	Deodorant / Aerosol spray	Lysol and Old spice Deodorant (High Endurance) were sprayed 5 seconds, off for 5 seconds, then sprayed for 5 seconds at location 4 and 1. The ventilation was off during the test. ~255 seconds after DAQ start old spice sprayed at location 4 ~290 seconds after DAQ start Lysol sprayed at location 4 ~325 seconds after DAQ start old spice sprayed at location 1 ~360 seconds after DAQ start Lysol sprayed at location 1 and

		test secured.
VS4-67	Flash Photography	Flashes from a camera were taken though out the test space, Locations 2,1 and 3 following the script from VS3. Ventilation was set on High. ~240 seconds after DAQ start photos were taken at location 1 causing a flash. ~80 seconds after source initiation flashes were taken at location 1 ~200 sec after source start flashes were taken at location 3. ~200 sec after source started red luminance indicator came on (sony camera). ~320 sec after initial source began flashing facing port red light seen on camera 4. ~360 sec after initial source began flashing secured.
VS4-68	IPA spill fire with trash bag	250 ml of IPA was poured on the deck forming a pool. A trash bag was placed by the pool in location 2. Ventilation was on and set to 5 ACH. ~ 240 sec after DAQ start pool was ignited with a butane lighter. ~ 45 sec after ignition the trash bag was involved. 250 sec after ignition the IPA spill fire was out. ~525 sec after ignition safety secured fire.
VS4-69	Smoldering Cable bundle	A cable bundle was placed at location 7 on the deck. Ventilation was set to 5 ACH. ~240 sec after DAQ start source was initiated by energizing heater cartridge to 84VAC ~285 sec after source initiation smoke visible from cable. ~ 25 minutes after source initiation voltage increased to 100 VAC and cable bundle transitioned to flaming fire. ~ 26 minutes and 30 sec after source initiation flame self extinguished ~29 minutes and 50 seconds after start of source cable bundle secured.
VS4-70	Flaming Cardboard boxes	Cardboard boxes were filled with polystyrene pellets and set on an elevated surface (3'9") at location 7. Ventilation was set to 5 ACH. ~300 sec after DAQ start boxes were ignited with lighter and a sustained flame was created. ~330 sec after ignition of boxes the fire was secured.
VS4-71	Pipe Rupture (gash)	A 1" pipe with a 10" by 1/8" gash was placed at location 4 facing a mattress. The mechanical ventilation was set to 5 ACH. ~240 sec after start of DAQ rupture was started. ~360 sec after DAQ start rupture secured.
VS4-72	Pipe Rupture	A 1" pipe with a 10" by 1/8" gash was placed at location 4 facing a mattress. The mechanical ventilation was set to 5 ACH.

	(gash)	~240 sec after start of DAQ rupture was started. ~360 sec after DAQ start rupture secured.
VS4-73	Changing light conditions	Lighting in the compartment was on during the baseline. ~240 sec after DAQ start lights turned off.
VS4-74	Changing light conditions	Lighting in the compartment was off during the baseline. ~240 sec after DAQ start lights turned on. ~340 sec after DAQ start announcement made on 1-MC.
VS4-75	Flaming Trash Can	The trash can was placed on the deck at Location 2. Ventilation was set to 5 ACH. The lights in the compartment were shutoff during the test. ~278 sec after DAQ start the fire was started. *Data secured before fire was extinguished
VS4-76	Flaming Cardboard boxes	Cardboard boxes were filled with polystyrene pellets and set on the deck at location 2. Ventilation was set to High (LPES). Lights in the compartment were off during entire test. ~290 sec after DAQ start boxes were ignited with lighter ~280 sec after ignition of boxes black smoke emitted from source. *Data secured before fire was extinguished
VS4-77	Grinding steel	A steel plate was painted and placed on the deck at location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start grinding was initiated with a 4 inch grinder. ~355 sec after grinding began grinding was secured.
VS4-78	Adjacent Space Fire	A heptane spray fire located in the radio transmitter room adjacent to the 3rd deck magazine impinged on the common bulkhead. Ventilation was set to 5 ACH and the 1-15-2 exhaust fans were running. ~115 sec after DAQ start the tell tale was lit. ~255 sec after DAQ start the adjacent space fire was initiated. The nozzles were pressurized with heptane at 50 psi. The starboard nozzle was not flowing well. ~120 sec after start of flow pressure was increased to 70 psi. ~340 sec after start of flow glow from bulkhead apparent of nightshot camera and a light smoke layer apparent in the overhead. ~430 sec after start of flow safety reports that the starboard nozzle has a good spray pattern. ~970 sec after start of flow fuel secured.
VS4-79	Pipe Rupture	A sprinkler head was attached to a 1" pipe, at location 9, 1 m above the deck. The mechanical ventilation was set to 5 ACH. The head was supplied with water at 40 psi. ~240 sec after DAQ start pipe rupture was started. ~360 sec after DAQ start rupture secured.
VS4-80	Flaming	The trash can was placed on the deck at Location 2. Ventilation

	Trash Can	was set to 5 ACH. Lights on in the compartment at the start of DAQ. ~240 sec after DAQ start lights in the compartment were turned off. ~300 sec after start of DAQ fire started. ~8 minutes and 40 sec after ignition compartment lights turned on. ~11 minutes and 30 sec after ignition fire extinguished.
VS4-81	Flash Photography	Flashes from a camera were taken though out the test space. Ventilation was set to 5 ACH. ~260 seconds after DAQ start source was initiated. 4 people taking photos at location 1. ~60 sec after source start flashes were secured at location 1. ~180 sec after source started flashes were started at location 4. ~240 sec after initial source began flashing at location 4 was secured.
VS4-82	Flaming Cardboard boxes	Cardboard boxes were filled with polystyrene pellets and set on top of a metal stand (3'9" high) at location 7. Ventilation was set to 5 ACH. ~240 sec after DAQ start boxes were ignited with lighter ~25 sec after ignition boxes were re-ignited. ~90 sec after ignition flames diminished and a steam of white smoke. ~200 sec after ignition of boxes flame visible again. ~260 sec after ignition boxes fully involved. ~340 sec after ignition black smoke visible. ~460 sec after ignition fire extinguished.
VS4-83	Welding (100A)	Welding was conducted at Location 5. Ventilation was set to 5 ACH. ~240 sec after DAQ start welding was initiated. ~45 sec after start of welding first rod completed ~60 sec after start of welding second rod started. ~115 sec after start of welding second rod completed ~125 sec after start of welding third rod started. ~190 sec after start of welding third rod completed and welding secured.
VS4-84	Smoldering Cable Bundle	A cable bundle was placed at location 3 on the deck. Ventilation was shutoff. ~240 sec after DAQ start source was initiated by energizing heater cartridge. ~ 150 sec after initiation of source smoke was visible from source. ~ 25 minutes after source initiation voltage increased to 100 VAC. ~ 26 minutes after source initiation cable bundle transitioned to flaming fire.

		~ 28 minutes after source initiation flame self extinguished ~30 minutes and 50 seconds after start of source cable bundle secured.
VS4-85	Grinding steel	A steel plate was painted and placed on the deck at location 5. Ventilation was set to 5 ACH. ~240 sec after DAQ start grinding was initiated with a 4 and ½ inch grinder. ~ 58 sec after initiation of grinding sparks visible from cameras at VS locations 1 and 2. ~420 sec after initiation of grinding, grinding was secured momentarily. 480 sec after grinding began grinding secured.
VS4-86	Smoldering Oily rags	Five 14" by 14" rags were soaked with ~1oz of oil each and placed in a trash can with a heater cartridge at location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start heater was energized to 85 VAC. ~180 sec after source start light smoke was visible. ~13 minutes and 20 sec after source start rags transitioned to a flaming fire. ~13 minutes and 10 sec after source start power was secured and source was extinguished
VS4-87	Pipe Rupture (gash)	A 1" pipe with a 10" by 1/8" gash was placed at location 9 facing the starboard bulkhead and supplied with water at 40 psi. The mechanical ventilation was set to 5 ACH. ~240 sec after start of DAQ rupture was started. ~360 sec after DAQ start rupture secured.
VS4-88	Flaming Cardboard boxes	Cardboard boxes were filled with polystyrene pellets and placed on the deck at location 2. Ventilation was set to 5 ACH. ~240 sec after DAQ start lights were turned off in compartment. ~ 300 sec after DAQ start boxes were ignited with lighter ~360 sec after ignition of boxes lights were turned back on in the compartment. ~420 sec after source ignition fire was extinguished.
VS4-89	Torch cutting steel	The torch cutting was conducted on the deck at Location 5. Ventilation was set to 5 ACH. ~240 seconds after DAQ start torch cutting was initiated. Popping noises could be heard from the torch and steel dropping to the deck. ~170 sec after torch cutting had been initiated torch went out and had to be re-lit. ~180 sec after torch cutting began (10 sec after torch went out) cutting resumed. ~300 seconds after torch cutting began announcement over 1-MC ~360 seconds after torch cutting began torch was secured.

VS4-90	Ventilation test and Welding (100 A)	The welding was conducted on the deck at Location 3. At DAQ start ventilation was initially off. ~180 seconds after DAQ start ventilation turned on at low setting (5ACH) ~360 sec after DAQ start ventilation increased to high (LPES) ~540 sec after DAQ start ventilation returned to low (5 ACH) ~12 minutes after DAQ start welding initiated. ~55 sec after start of welding first rod completed ~70 sec after start of welding second rod started. ~140 sec after start of welding second rod completed ~155 sec after start of welding third rod started. ~215 sec after start of welding third rod completed ~230 sec after start of welding forth rod started. ~290 sec after start of welding second rod completed ~300 sec after start of welding the welding was secured.
VS4-91	Hot metal surface	A two-sided box (2 ft by 2 ft), see photos, was heated with a methanol pool fire (pan size 1 ft by 1 ft) with ~ 1.5 L of methanol. The box was positioned port of location 4 at location 7. Ventilation was set to 5 ACH. ~240 sec after DAQ start pool fire ignited, flame visible on both CCTV and Nightshot cameras at VS location 1. ~74 sec after ignition fire secured
VS4-92	TIG welding	The TIG welding was conducted on a elevated surface at Location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start TIG welding initiated. ~194 sec after welding started there was a momentary stop. ~212 sec after welding started the momentary stop ended. ~240 sec after welding stated it was secured.
VS4-93	Pipe Rupture	BETE P-80 nozzle used with open orifice, no deflector. The nozzle was placed at location 4 and test was run with no mechanical ventilation. ~15 minutes 25 sec nozzle clogged so it was removed with water gushing onto the deck. ~18 minutes after start of DAQ valve opened with new head in place (40 psi) ~20 minutes after DAQ start pressure increased ~20 minutes 45 sec after DAQ start pressure increased to 149 psi. ~23 minutes after DAQ start rupture secured.
VS4-94	Smoldering Laundry	The Laundry was placed on the deck at Location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start cartridge heater started. ~39 sec after heater started variac adjusted from 85 to 97VAC. ~100 sec after heater started smoke visible from source ~200 sec after heater started smoke haze visible in OH. ~623 sec after heater started source transition while being

		secured.
VS4-95	Smoldering Laundry	Camera 4 was tilted up so that the OH light is in the cameras field of view. The trash can was placed on the deck at Location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start cartridge heater started. ~90 sec after heater started smoke visible from source ~190 sec after heater started smoke haze visible in OH.
VS4-96	Flaming Trash Can	Camera 4 was tilted up so that the OH light is in the cameras field of view. The trash can was placed on the deck at Location 3. Ventilation was set to 5 ACH. ~240 sec after DAQ start trash can fire was started with a lighter. ~18 sec after fire started flame visible from VS2 ~180 sec after fire started smoke visible going into OH. ~220 sec after fire started steady smoke visible from trash can.
VS4-97	Smoldering Laundry	The Laundry was placed on the deck at Location 4. Ventilation was set to 5 ACH. ~240 sec after DAQ start cartridge heater started. ~82 sec after heater started smoke visible from source ~222 sec after heater started smoke haze visible in OH.
VS4-98	Space Heater	The heater was at Location 4 facing Port when the test began. Ventilation was set to 5 ACH. ~240 sec after DAQ start heater started. ~70 sec after heater started hot surface visible from Camera 1 ~170 sec after heater started hot surface visible from Camera 4
VS4-99	Toaster	The toaster was at Location 4 on top of a 55-gal drum visible to volume sensor locations 1 and 3. Ventilation was set to 5 ACH. ~240 sec after DAQ start toaster started ~205 sec after start of toaster the toast popped.
VS4-100	Space Heater	The heater was at Location 8 facing Starboard when the test began. Ventilation was set to 5 ACH. ~240 sec after DAQ start heater started. ~46 sec after heater started hot surface visible from Camera 2 ~150 sec after heater started hot surface visible from Camera 5